This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

[illegible] miscellaneous.

[illegible]

[illegible]

VOL. I.

[illegible] Investigations. [illegible] [illegible] [illegible] tions, [illegible] Division, [illegible] No. [illegible] 190[illegible].

[illegible] [illegible] Bulletin No. [illegible], 190[illegible].

[illegible] Southern California [illegible], 190[illegible].

[illegible] of [illegible] [illegible] [illegible], [illegible] U. S. Dept. of Agriculture, [illegible] 19[illegible].

[illegible] tion of the [illegible] [illegible] [illegible] Inland Water Navigation. By [illegible] [illegible] H. Morton. U. S. Dept. of

---

[illegible]

[illegible] forest influences.

[illegible] PAMPHLET 15.

FOREST INFLUENCES

VOL. I.

Forest Influences. U. S. Department of Agriculture, Forestry Division, Bulletin No. 7. 1893.

Forest Soils: [illegible] U. S. Department of Agriculture, [illegible] Bulletin No. [illegible], [illegible].

[illegible] The [illegible] of [illegible] Southern California [illegible], [illegible].

Surface Conditions and Stream Flow. By W. L. Hall, and H. Maxwell, [illegible] U. S. Dept. of Agriculture, Circular 176.

The Relation of the Southern Appalachian Mountains to Inland Water Navigation. By M. O. Leighton and A. H. Horton. U. S. Dept. of

SD425
F3
v.1

The Relation of Forests to Stream Flow. By

James W. Toumey. Reprint from Yearbook

of Department of Agriculture for [illegible].

Influence of Forestry upon the Lumber Industry.

By Overton W. Price. Reprint from Year-

book of Department of Agriculture, [illegible].

The Mississippi River Flood. U. S. Dep't. of

Agriculture, Misc. Circular No. [illegible]

A Working Erosion Model for Schools. By Don

Carlos Ellis, [illegible]. U. S. Department of

Agriculture, Office of Experiment Stations

Circular No. 117.

Washtenaw County [illegible]

Michigan Horticultural Society, [illegible].

The Forest, its Influence and [illegible]. By

Fred W. Card. Forest Influences. Rhode

Island Agricultural Station Bulletin, [illegible].

Some Forest Influences. By Filibert Roth,

Professor of Forestry, University of

Michigan.

Talks on the Subject of Forestry [illegible]

338428

U.S. DEPARTMENT OF AGRICULTURE.
FORESTRY DIVISION.
BULLETIN No. 7.

Walter Mulford

FOREST INFLUENCES.

1. INTRODUCTION AND SUMMARY OF CONCLUSIONS. By B. E. FERNOW.
2. REVIEW OF FOREST METEOROLOGICAL OBSERVATIONS: A STUDY PRELIMINARY TO THE DISCUSSION OF THE RELATION OF FORESTS TO CLIMATE. By M. W. HARRINGTON.
3. RELATION OF FORESTS TO WATER SUPPLIES. By B. E. FERNOW.
4. NOTES ON THE SANITARY SIGNIFICANCE OF FORESTS. By B. E. FERNOW.

APPENDICES.

1. DETERMINATION OF THE TRUE AMOUNT OF PRECIPITATION AND ITS BEARING ON THEORIES OF FOREST INFLUENCES. By CLEVELAND ABBE.
2. ANALYSIS OF RAINFALL WITH RELATION TO SURFACE CONDITIONS. By GEORGE E. CURTIS.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1902.

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
FORESTRY DIVISION,
Washington, D. C., November 1, 1892.

SIR: I have the honor to submit herewith for publication a review of the meteorological observations which have been made, mostly in foreign countries, for the purpose of determining whether and to what extent forests influence climate, together with a discussion of the manner in which forests affect the water conditions of the earth and other matter elucidating the question of forest influences in general.

Respectfully,

B. E. FERNOW,
Chief of Division.

Hon. J. M. RUSK,
Secretary of Agriculture.

TABLE OF CONTENTS.

PAGE.

I. Forest influences: Introduction and summary of conclusions, by B. E. Fernow 9
  Introduction 9
  Summary of conclusions 13
    General considerations 13
    Difference of meteorological conditions within and without the forest 14
      Soil temperatures 14
      Air temperatures under the crowns 14
      Air temperatures within the crowns 15
      Air temperatures above the crowns 15
      Air temperatures in general 15
      Humidity of air 16
    Influence of forests upon the climate of the surrounding country 17
    Influence of forests upon water and soil conditions 20
    Sanitary influence of forests 21

II. Review of forest meteorological observations: A study preliminary to the discussion of the relation of forests to climate. By M. W. Harrington 23
  The nature of the problem 23
  Systematic observations in forest meteorology 26
    France 27
    Germany 30
    Sweden 31
    Austria 33
  Objects and methods 35
  Soil temperatures 40
  Temperatures of the air in the interior of forests 51
    Annual range 51
    Monthly range 53
    Deciduous and evergreen forests 58
  Temperature in the tree-crown and above trees 61
    Temperature gradients 68
    Temperature above forests 69
  Tree temperatures 72
  Vegetation and air temperatures 76
    Theoretical calculation of heat absorption 80
  Temperatures in woods, glades, and plains 83
    Conclusions regarding temperatures within and without forests 88
  Temperatures in wooded and treeless territories 89
  Relation of evaporation to forests 96
  Forests and humidity 102
  Rainfall in, above, and near forests 106
  Precipitation over wooded and treeless districts 111
  Forests, wind, and storms 118
    Influence of forests on fogs and clouds 121
    Influence of forests on hailstorms and blizzards 121

PAGE.
III. Relation of forests to water supplies. By B. E. Fernow 123
The total water supply 123
Influence of forests upon precipitation 125
Results of observations near Nancy, France 126
Results obtained in Bohemia 126
Results of observations in India and Brazil 128
Supposed influence of forests upon hailstorms 129
Influence of forests upon the disposition of the water supply 130
Elements of dissipation 130
Interception 130
Evaporation 132
Transpiration 136
Elements of conservation 137
Effects of forests in case of snow 137
General effect of forests in reducing evaporation 138
Summation of the conservative and dissipative influences 140
Distribution of terrestrial waters 141
Analysis of determining influences 141
Water capacity and water conductivity of soils and soil-covers ... 144
Water conductivity of soils 148
Formation of springs and conditions affecting their flow 153
Influence of forests upon surface drainage 157
Retardation of the waterflow 158
Experience in the French Alps 159
Examples of the influence of forests on waterflow 162
IV. Notes on the sanitary significance of forests. By B. E. Fernow 171

APPENDICES.

I. Determination of the true amount of precipitation and its bearing on theories of forest influences. By Cleveland Abbe 175
Relation of pattern and altitude of gauges to accuracy of rainfall measurements 176
Elimination of errors of the rain gauge 180
Variations in geographical distribution of rainfall 182
Chronological variations of rainfall 184
Recommendations 185
Application to forestry 185
II. Analysis of the causes of rainfall with special relation to surface conditions. By George E. Curtis 187
Climatic illustrations 189

LIST OF ILLUSTRATIONS.

FIGS. PAGE.

1. Differences of mean annual temperatures of soil (W—O)................ 42
2. Difference of temperature (W—O) at the depth of 4 feet............... 44
3. Difference of soil temperature (W—O), all stations—German observatories. 45
4. Differences of soil temperature (woods and open fields). Comparison of deciduous and evergreen trees (W—O)........................ 47
5. Differences of soil temperature (woods and open fields). Comparison of elevations above sea level (W—O)............................ 48
6. Differences of temperature for young trees, Lintzel Station, woods and open fields (W—O).. 49
7. Effects of litter on soil temperature (littered surface—bare). Wollny's observations.. 49
8. Difference of soil temperature, under sod and bare surface (sod—bare). Becquerel's observations.................................... 50
9. Forest air temperature differences, W—O. German stations............ 52

10, 11, 12, 13, 14, 15, 16, and 17. Forest air temperature differences, woods and open fields (W—O), at Friedrichsrode, Hagenau, Sonnenberg, Eberswalde, Schoo, Marienthal, Hadersleben, and average................ 55, 57

18, 19, 20, 21, and 22. Forest air temperature, difference of woods and open fields (W—O), deciduous trees, evergreen trees, elevated stations, near sea level, and young forest (Lintzel)............................ 59

23. Forest air temperature differences for the year at height of the tree top (W—O).. 62

24, 25, 26, 27, 28, 29, 30, 31, and 32. Tree-top temperature, differences (W—O) at Friedrichsrode, Eberswalde, St. Johann, Carlsberg, Sonnenberg, Kurwien, Hagenau, Schoo, Neumath.......................... 64, 65

33. Average differences of tree-top temperature, sixteen German stations (W—O).. 66
34. Tree-top temperature differences for four stations, with average height of 24 feet... 66
35. Tree-top temperature differences for four stations, with average height of 46 feet... 67
36. Tree-top temperature differences, German stations (W—O), deciduous trees... 67
37. Tree-top temperature differences, German stations, evergreen trees...... 67
38. Vertical temperature, gradient in woods, degrees Fahrenheit for a hundred feet... 68
39. Forest temperature differences at Halatte under deciduous forest........ 69
40. Forest temperature differences at Ermenonville under pines, soil, coarse bare sand... 70
41. Forest temperature differences above trees, from Fautrat's observations. 70
42. Vertical temperature gradients from observations above trees........... 70
43. Tree temperature, Geneva observations.............................. 73
44. Temperature differences between tree and air........................ 74

PAGE.
45. Differences of mean annual temperature between woods and glade, and woods and plains, Swedish observations 85
46. Difference of air temperature in forest, glade, and plain (Swedish) 86
47. Amplitude of W—G (lower curve) and W—O (upper curve) Swedish observations 87
48. Differences of soil temperature at 20 inches depth 87
49. Evaporation and precipitation 96
50. Monthly evaporation in the fields (upper curve) and woods (lower curve), in inches 97
51. Percentage of evaporation in the woods as compared with that in open fields 97
52. Ratio of evaporation from water surface in fields (upper curve) and forest (lower curve) to precipitation (top line) 97
53. Percentage of evaporation in woods to that in the open air 98
54. Percentage of precipitation, received under trees (all kinds), German observations 106
55. Percentage of precipitation, received under trees (different kinds) 107
56. Precipitation through trees at Cinq Franchées and Bellefontaine 108
57. Snow bank before and behind a fence 119
58. Forest circulation 120
59. Day circulation 120
60. Night circulation 120
61. Standing or ground-water spring 154
62. "Fissure" spring 155
63. Cavern spring 155

NOTE.

The diagrams for the paper on Forest Meteorological Observations are explained in the accompanying text. They are of the usual and familiar kinds except the *Forest Temperature Diagrams* (Figs. 10–22, 24–41, 46), which are novel and will repay careful study. In these cases the base line of the diagram is the line of no difference in temperature, as compared with open fields, glades, or plains (*i. e.*, $W-O=0$, $W-G=0$, or $W-P=0$). When the woods are cooler the line for the woods falls below this base line ($W-O$, etc., is negative); when warmer, above ($W-O$, etc., is positive). The part of the year in which the woods are cooler is usually shaded. For a more complete explanation see pages 53 and 54.

FOREST INFLUENCES.

1.—INTRODUCTION AND SUMMARY OF CONCLUSIONS.

By B. E. Fernow.

INTRODUCTION.

One of the arguments upon which a change of policy in regard to our forests, and especially on the part of the National Government, is demanded, refers to the influence which it is claimed forest areas exert upon climate and waterflow. It is argued that the wholesale removal and devastation of forests affects climate and waterflow unfavorably.

Popular writers on forestry, friends of forestry reform, and the public mind have readily taken hold of this proposition, enlarged upon it, and generalized without sufficient and relevant premises, and before it was possible for science and systematic observations to furnish grounds or sound deductions; hence we have had only presumptions supported by superficial reasoning and occasional experiences. Even scientific writers have discussed the question without proper basis, and have sought to reason out the existence or absence of such an influence upon general premises and such evidence as the history of the world seemed to furnish, or else upon observations which were either of too short duration to allow elimination of other disturbing factors or else were otherwise unreliable.

From the complication of causes which produce climatic conditions it has always been difficult to prove, when changes of these conditions in a given region were observed, that they are permanent and not due merely to the general periodic variations which have been noted in all climates of the earth, or that they are due to a change of forest conditions and to no other causes; hence some climatologists have thought proper to deny such influences entirely. On the other hand, there are as trustworthy and careful observers who maintain the existence of such influences; but only of late has the question been removed from the battle field of opinions, scientific and unscientific, to the field of experiment and scientific research, and from the field of mere speculation to that of exact deduction. But the crop of incontrovertible facts is still scanty, and further cultivation will be necessary to gather a fuller harvest and then to set clear the many complicated questions connected with this inquiry.

Meanwhile a thorough beginning with a view to settle the question by scientific methods and careful systematic measurements and observations has been made in Europe, where the existence of well-established forest administrations, manned with trained observers, has rendered practicable the institution of such work on an extensive scale—the only one which can yield adequate results. Notably the observations made at the duplicate stations in Prussia, and recorded for fourteen successive years, furnish reliable material for the discussion at least of the relation of forest cover to meteorological phenomena, and from these in time the nature and extent of any influence upon the climate, if such exists, may be determined.

Prof. M. W. Harrington, now Chief of the Weather Bureau, has, in the following pages, compiled these and other observations, and in an ingenious manner has compressed them into graphic illustrations, which readily convey the results to the reader. While an attempt has been made to discuss the problems and records in popular form, the student of forest meteorological problems will find not less useful the clear and unbiased statements of what these problems involve and what the records do and do not show.

It may be proper to call attention to and accentuate the fact that the question of practical importance is not so much as to the effects upon the general climate, but as to the local modification of climatic conditions which a forest area may produce.

It can not be too strongly impressed upon those who disclaim any influence of forest cover on climate, because the cosmic causes by which this is produced are immeasurably greater, that there are two classes of climate always to be considered separately, namely, the general climate and the local climate. The latter is of most importance to us, and alone can be modified by small causes. We modify it by building a house around us, thus altering the temperature and moisture conditions of the atmosphere so inclosed; but the question is, whether we can alter these conditions on a larger scale by such means as alternating forest areas and fields or by large bodies of forest. We are not so much concerned as to whether the total rainfall over the continent is increased, but whether the distribution of precipitation in time and quantity over and near a forest area is influenced by its existence; whether we or our crops feel its absence or presence in our immediate neighborhood; whether the protection it seems to afford and the changes it seems to produce in the meteorological phenomena are or are not real and of sufficient magnitude to influence our forest policy.

We would here call special attention to the memoir of Prof. Cleveland Abbe, contained in this bulletin, from which the difficulty of obtaining accurate records of rainfall with the gauges in general use is apparent. When we find our means of measurement so deficient we must be careful how far we base conclusions on their records.

In this connection the very suggestive paper by Mr. George E. Curtiss, contained in this bulletin, should receive attention. His classification of rains into convective, orographic, and cyclonic will certainly assist in developing true conceptions as to cause and effect and possible relation of surface conditions to rainfall.

While, then, conclusive deductions may perhaps not be as yet admissible, we can not refrain from pointing out the results obtained in the forest station at Lintzel (recorded on page 113), which seem to show that forest-planting did, under the conditions there prevailing, produce a considerable change in meteorological conditions.

We can understand readily that if any influence exists it must be due, in the first place, to the mechanical obstruction which the forest cover presents to the passage of air currents and to the action of the sun's rays upon the soil—it must result from a difference in isolation and consequent differences in temperature and evaporation over forest and field. It is also readily understood that the influence can become appreciable only when large enough areas exhibiting such differences are opposed to each other, capable of producing local currents of air which may intercommunicate the characteristics of the one area to the other. The size and character of the forest growth, its density, height, situation, and composition, are, therefore, much more important in determining its influence than has been hitherto supposed. It is not trees, but masses of foliage, which may be effective. A large sheet covering an extended area from the influence of the sun would produce almost the same differences in meteorological conditions that a forest cover is expected to produce.

While, then, we may admit *a priori* that extent or area and condition of the forest cover are important, we have as yet no data from which to calculate any proper size or proportion, and the attempts to fix a certain percentage of forest cover needed for favorable climatic conditions of a country are devoid of all rational basis.

Leaving the question of forest influences upon climate as still awaiting final solution, we may speak with much more confidence of the effect which forest cover exerts upon the disposal of water supplies. This effect can be much more readily studied and shows itself much more conspicuously. It is perhaps also much more important to human economy, for it is becoming more and more apparent that our agricultural production is dependent not so much upon the amount of rainfall as upon the proper disposal of the waters that fall.

Recognizing this truth, the American Association for the Advancement of Science, in 1891, sent the following resolution to the Secretary of Agriculture:

> The American Association for the Advancement of Science respectfully submits for the consideration of the Secretary of Agriculture that the future of successful and more productive agriculture depends very largely upon a rational water manage-

ment, meaning thereby not only the use of water for irrigation in the arid and subarid regions, but the rational distribution and use in the humid regions of available water supplies by means of horizontal ditches and irrigation systems, combined with proper mechanical preparation of the soil, and with drainage systems, with the object of fully utilizing the water for plant production and providing for the safe and harmless removal of the surplus.

The present policy of forest production and of allowing our waters to run to waste not only entails the loss of their beneficial influence upon plant production, but permits them to injure crops, to wash the fertile mold from the soil, and even to erase and carry away the soil itself.

It is upon these considerations that the association respectfully suggests to the honorable Secretary the desirability of utilizing the Weather Bureau, the various agricultural experiment stations, and other forces, in forming a systematic service of water statistics, and in making a careful survey of the condition of water supplies, which may serve as a basis for the application of rational principles of water management.

How poorly we understand the use of these supplies is evidenced yearly by destructive freshets and floods, with the accompanying washing of soil, followed by droughts, low water, and deterioration of agricultural lands.

It may be thought heterodox, but it is nevertheless true that the manner in which most of the water of the atmosphere becomes available for human use (namely, in the form of rain) is by no means the most satisfactory, not only on account of its irregularity in time and quantity, but also on account of its detrimental mechanical action in falling; for in its fall it compacts the ground, impeding percolation. A large amount of what would be carried off by underground drainage is thus changed into surface-drainage waters. At the same time by this compacting of the soil capillary action is increased and evaporation thereby accelerated. These surface waters also loosen rocks and soil, carrying these in their descent into the river courses and valleys, thus increasing dangers of high floods and destroying favorable cultural conditions.

Here it is that water management and, in connection with it or as a part of it, forest management should be studied; for *without forest management no rational water management is possible.* The forest floor reduces or prevents the injurious mechanical action of the rain and acts as a regulator of water flow. Hitherto water management in rainy districts has mainly concerned itself with getting rid of the water as fast as possible, instead of making it do service during its temporary availability by means of proper soil management, horizontal ditches and reservoirs—drainage and irrigation systems combined. It seems to have been entirely overlooked that irrigation, which has been considered only for arid and subarid regions, is to be applied for plant production in well-watered regions with equal benefit and profit, if combined with proper drainage systems and forest management. A discussion of the manner in which the forest influences the disposal of water supplies has been made a special part of this publication.

It will be observed in this bulletin that the historical method of discussing the subject of forest influences, which consists in adducing general observations throughout the world, has given place to the scientific method, which relies upon specific observations and experiments and upon the application of well-established physical laws to the explanation of the facts observed.

SUMMARY OF CONCLUSIONS.

For those who wish to know only what the present state of the question of forest influences is, we have summarized what conclusions may be drawn from the facts presented in this bulletin, referring them to the body of the report for the basis of these conclusions and the discussion *in extenso*. This arrangement, we are aware, is not customary and logical, but since the object of this bulletin, to some extent, is to familiarize not only the student but the general public with the subject, it seemed expedient to meet the convenience of the general reader in this manner. For easy reference the pages of this bulletin containing the data upon which each conclusion is reached are given in parentheses at the end of each paragraph.

GENERAL CONSIDERATIONS.

(1) We must keep separate two main questions, namely, What is the difference of conditions within and without the forest? and How far is the difference of conditions within the forest communicated to the outside, *i. e.*, how far does the forest influence the conditions outside? (Pp. 23-40.)

(2) The general climatic conditions in which the forest is situated as well as its situation with reference to elevation and exposure, furthermore its composition, whether evergreen or deciduous, its destiny, its height and extent, the character of the forest floor, and other features which determine its quality, must all combine in producing variety, at least quantitatively, both as to difference of conditions within and without the forest and as to possible exchange of the same, and hence the question of forest influences can be properly discussed only with reference to these other conditions. We must refrain from generalizing too readily from one set of conditions to another set of conditions. (Pp. 40-121.)

(3) In the matter of forest influence upon waterflow, besides the above mentioned, other conditions, the topography and geology or stratification of soil, must also be taken into account and generalizations without regard to these must be avoided. (Pp. 123-157.)

(4) No influence upon the general climate which depends upon cosmic causes can in reason be expected from a forest cover. Only local modifications of climatic conditions may be anticipated; but these modifications if they exist are of great practical value, for upon them

rest success or failure in agricultural pursuits and comfort or discomfort of life within the given cosmic climate. The same condition must be insisted upon with reference to forest influences upon waterflow, which can exist only as local modifications of water conditions, which are due in the first place to climatic, geologic, and topographic conditions. (Pp. 157–170.)

DIFFERENCE OF METEOROLOGICAL CONDITIONS WITHIN AND WITHOUT THE FOREST.

(1) *Soil temperatures.*—The general influence of the forest on soil temperatures is a cooling one, due to the shade and to the longer retention of moisture in the forest floor as well as in the air, which must be evaporated before the ground can be warmed. As a consequence the extremes of high and low temperature within the forest soil occur much later than in the open, and both extremes are reduced, but the extreme summer temperatures much more than the winter temperatures. (Pp. 40–46.)

The difference between evergreen and deciduous forests, which almost vanishes in the winter time, is in favor of the deciduous as a cooling element in summer and autumn, while during spring the soil is cooler under evergreens. The effect increases naturally with the age and height of the trees. (Pp. 46–50.)

(2) *Air temperatures under the crowns.*—The annual range of air temperature is smaller in the forest than in the open; the effect upon the minimum temperature (*i. e.*, the effect in winter) is less than on the maximum temperature (*i. e.*, the effect in summer). The combined effect is a cooling one. The range of temperature is more affected than the average absolute temperature, or, in other words, the moderating influence is greater than the cooling effect. (Pp. 51–53.)

The monthly minima for middle latitudes are uniformly reduced during the year, and the monthly maxima are much more reduced during the summer than during the winter. On the average the forest is cooler than the open country in summer, but about the same in winter, with a slight warming effect in spring. (Pp. 53–58.)

The difference between the mean monthly air temperatures in the woods and in the open varies with the kind of forest much more than is the case for soil temperatures. The evergreen forest shows a symmetrical increase and decrease throughout the year. The deciduous forest shows a variable influence which diminishes from the midwinter to springtime, but increases rapidly as the leaves appear and grow, becoming a maximum in June and July and then diminishing rapidly until November. The annual average effect is about the same both for evergreens and deciduous forests. (Pp. 58–60.)

Forests situated at a considerable elevation above the sea have sensibly the same influence on the reduction of the mean temperature as do forests that are at a low level. (P. 60.)

Young forests affect the air temperature very differently from mature forests; in the former the minimum temperatures are always reduced, but the maxima are exaggerated. The observations on which this conclusion is based ought, perhaps, to be considered as pertaining rather to the case of temperatures in the tree tops. (P. 60.)

(3) *Air temperatures within the crowns.*—The mean temperature of the air in the tree tops, after correcting for elevation above ground, is rather higher than over open fields. The effect of tree tops does not appreciably depend upon the height of the station above ground. The effect upon the minima is generally greater than on the maxima, the total effect being a warming one. A tree top station is in general intermediate, as to temperature, between a station near the ground in the forest and one in the open field. (Pp. 61–66.)

Evergreen forests show less difference between the temperature in the crown and below, and altogether more uniformity in temperature changes throughout the year than deciduous growth. (P. 67.)

The vertical gradient for temperature within the forest, on the average, of all stations and all kinds of forest trees is large, varying from 0.61° F. per 100 feet in April to 2.50° F. in July. (P. 68.)

A reversal of the vertical gradient, namely, a higher temperature above than below, occurs in the wood, especially in the summer time. It also occurs in the open air regularly at night, and may be three or four times as large as that just mentioned. In general, the action of the forest tends to produce a vertical distribution of temperature, like that over snow or level fields on clear nights. (P. 69.)

(4) *Air temperature above the crowns.*—The temperature at considerable heights above the forests appears to be slightly affected by the forest, and more so with evergreens than with deciduous growth. The vertical gradients of temperature within 30 feet above the tops of the trees are all reversed throughout the leafy season; the gradients are also greater above the tree crown than below, at least during the clear sky and calm air. The wind affects the temperature under and within the crowns, but makes little difference above them. The surface of the forest crown appears meteorologically much like the surface of the meadow or cornfield. It is as if the soil surface has been raised to the height of the trees. (Pp. 69–72.)

(5) *Air temperature in general.*—From the preceding generalizations it appears that the forest affects the temperature just as any collection of inorganic obstacles to sunshine and wind; but as an organic being the forest may be also an independent source of heat. Careful observations of the temperature within the trunk of the tree and of the leaves of the tree show that the tree temperature is affected somewhat by the fact that the rising sap brings up the temperature of the roots, while the return sap from the leaves brings their temperature down, and the tree temperature, considered as the result of the complex adjustment, is not appreciably affected by any heat that may be evolved by the chemical processes

on which its growth depends. It is not yet clear as to whether the chemical changes that take place at the surface of the leaves should give out any heat; it is more likely that heat is absorbed, namely, rendered latent, especially in the formation of the seed; the process of germination usually evolves this latent heat; the immense quantity of water transpired and evaporated by the forests tends to keep the leaves at the same temperature as that of the surface of water or moist soil. (Pp. 73–95.)

(6) *Humidity of air.*—The annual evaporation within the forests is about one-half of that in the open field; not only is the evaporation within a forest greatest in May and June, but the difference between this and the evaporation in the open field is also, then, a maximum, which is the saving due to the presence of the woods. The average annual evaporation within the woods is about 44 per cent of that in the field. Fully half of the field evaporation is saved by the presence of the forest. (P. 96.)

The quantity of moisture thrown into the air by transpiration from the leaves in the forest is sometimes three times that from a horizontal water surface of the same extent, and at other times it is less than that of the water. The transpiration from leaves in full sunshine is decidedly greater than from leaves in the diffused daylight or darkness. The absolute amount of annual transpiration, as observed in forests of mature oaks and beeches in central Europe, is about one-quarter of the total annual precipitation. (Pp. 77, 78.)

The percentage of rainfall evaporated at the surface of the ground is about 40 per cent for the whole year in the open field, and about 12 per cent for the forest, and is greater under deciduous than under evergreen forests. (P. 98.)

The evaporation from a saturated bare soil in the forest is about the same as that from a water surface in the forest, other conditions being the same. (P. 99.)

The presence of forest litter like that lying naturally in undisturbed forests hinders the evaporation from the soil to a remarkable extent, since it saves seven-eighths of what would otherwise be lost. (P. 100.)

The total quantity of moisture returned into the atmosphere from a forest by transpiration and evaporation from the trees and the soil is about 75 per cent of the precipitation. For other forms of vegetation it is about the same or sometimes larger, varying between 70 per cent and 90 per cent; in this respect the forest is surpassed by the cereals and grasses, while on the other hand, the evaporation from a bare soil is scarcely 30 per cent of the precipitation. (P. 101.)

The absolute humidity within a forest exceeds that of the glades and the plains by a small quantity. The relative humidity in the forest is also larger than in the glades or plains by 2 per cent to 4 per cent. Forests of evergreens have from two to four times the influence in increasing relative humidity than do forests of deciduous trees. (Pp. 102–105.)

The gauges in European forest stations catch from 75 to 85 per cent when placed under the trees, the balance representing that which passes through the foliage and drips to the ground or runs down along the trunks of trees, or else is intercepted and evaporated. The percentage withheld by the trees and which either evaporates from their surface or trickles along the trunk to the ground is somewhat greater in the leafy season, though the difference is not great. Deciduous and evergreen trees show but slight differences in this respect. More rain is usually caught by gauges at a given height above the forest crown than at the same height in open fields, but it still remains doubtful whether the rainfall itself is really larger over the forests, since the recorded catch of the rain-gauge still requires a correction for the influence of the force of the wind at the gauge. (Pp. 106–110.)

In such cases where over a large area deforestation and reforestation have seemingly gone hand in hand with decrease and increase of rainfall, the possible secular change in rainfall must also be considered. Yet the experience of increased rainfall over the station at Lintzel (p. 113), with increase of forest area, points strongly toward a possible interdependence under given conditions. (Pp. 111–118.)

By condensing dew, hoar frost, and ice on their branches, trees add thereby a little to the precipitation which reaches the ground, and by preventing the rapid melting of snow more water remains available under forest cover. (P. 121.)

The question as to the march of destructive hailstorms with reference to forest areas, which seems settled for some regions in France, remains in doubt for other, especially mountain, regions. (Pp. 121–129.)

From these statements we would expect as a consequence of deforestation an effect on the climate of the deforested area in three directions, namely: (*a*) extremes of temperature of air as well as soil are aggravated; (*b*) the average humidity of the air is lessened, and possibly (*c*) the distribution of precipitation throughout the year, if not its quantity, is changed.

INFLUENCE OF FORESTS UPON THE CLIMATE OF THE SURROUNDING COUNTRY.

(1) An influence of the forest upon the climate of its surroundings can only take place by means of diffusion of the vapor which is transpired and evaporated by the crowns and by means of air currents passing through and above the forests being modified in temperature and moisture conditions; the mechanical effect upon such air currents by which they are retarded in their progress may also be effective in changing their climatic value.

(2) Local air currents are set up by the difference in temperature of the air within and without the forest, analogously to those of a lake or pond, cooler currents coming from the forest during the day in the lower strata and warmer currents during the night in the upper strata.

The latter currents, being warmer and moister, can be of influence on the temperature and moisture conditions of a neighboring field by moderating temperature extremes and increasing the humidity of the air.

This local circulation is the one most important difference between forest and other vegetation. How far away from the forest this circulation becomes sensible is not ascertained. In winter time, when the temperature differences become small, no such circulation is noticeable. (P. 120.)

(3) The general air currents in their lower portions are cut off entirely by the forest, which acts as a windbreak. This influence can of course be experienced only on the leeward side. How far this protection reaches it is difficult to estimate, but it certainly reaches farther than that of a mere windbreak, since by the friction of the air moving over the crowns a retardation must be experienced that would be noticeable for a considerable distance beyond the mere windbreak effect. Deforestation on a large scale would permit uninterrupted sweep of the winds, a change more detrimental where the configuration of the ground does not fulfill a similar function—in large plains more than in hilly and mountainous regions, and at the seashore more than in the interior. (Pp. 118–120, 133.)

The upper air strata can be modified only by the conditions existing near and above the crowns. At the same time they must carry away the cooler and moister air there and create an upward movement of the forest air, and thereby in part the conditions of this become also active in modifying air currents. The greater humidity immediately above the crowns is imparted to the air currents, if warm and dry, and becomes visible at night in the form of mists resting above and near forest areas. These strata protect the open at least against insolation and loss of water by evaporation, and have also a greater tendency to condensation as dew or light rain, if conditions for such condensation exist. This influence can be felt only to the leeward in summer time and with dry, warm winds, while the cooling winter effect upon comparatively warmer moist winds is not noticeable. Theoretical considerations lead to the conclusion that in mountain regions only the forest on the leeward slope can possibly add moisture to a wind coming over the mountain, but this does not necessarily increase the precipitation on the field beyond. Altogether the theoretical considerations are as yet neither proved nor disproved by actual observations, and as to rainfall the question of influence on the neighborhood is still less settled than that of precipitation upon forest areas themselves. Wherever moisture-laden winds pass over extensive forest areas the cooler and moister condition of the atmosphere may at least not reduce the possibility of condensation, which a heated plain would do; but observations so far give no conclusive evidence that neighboring fields receive more rain than they otherwise would. (Pp. 76, 83, 89, 103.)

(4) With regard to comparative temperatures in forest stations and open stations that are situated not far apart from each other, it would

appear that the forests exerts a cooling influence, but that more detailed conclusions are hindered by the consideration that the ordinary meteorological station itself is somewhat affected by neighboring trees.

The study of the stations in Asiatic and European Russia seems to show that in the western part of the Old World the presence of large forests has a very sensible influence on the temperature. Similar studies for stations in the United States seem to show that our thin forests have a slight effect in December but a more decided one in June. It appears also that our wooded regions are warmer than the open plains, but there is no positive evidence that this difference of temperature is dependent upon the quantity or distribution of forests, or that changes in temperature have occurred from this cause. (Pp. 94, 95.)

(5) When a forest incloses a small area of land, forming a glade, its inclosed position brings about special phenomena of reflection of heat, local winds, and a large amount of shade. For such forests it is found that the mean range of temperature is larger in the woods than on the open plains; the glade climate is more rigorous than the climate of open plains; the glade is cooler and its diurnal range larger during the spring, summer, and autumn. (Pp. 84–88.)

Favorable influences upon moisture conditions of the air are most noticeable in localities where much water is stored in underground with overlying strata which are apt to dry when our summer drought prevails. Here the forest growth is able to draw water from greater depths and by transpiration return it to the atmosphere, thereby reducing the dryness and possibly inducing precipitation. In most climates this action would be less effective or of no use. Hence in regions with oceanic climate with moist sea winds like England and the west coasts of Europe or of the northern United States, deforestation from a climatic point of view may make no appreciable difference, such as it would make in continental climates like the interior of our country, the Rocky Mountains, and southern California.

Whether large or small areas of forests and open fields alternating, or what percentage of forests is most favorable can not as yet be discussed, since we are not clearly informed even as to the manner and the amount of influence which forest cover exercises. In general we may expect that an alternation of large forested and unforested areas, in regions which on account of their geographic situation have a dry and rigorous climate, is more beneficial than large uninterrupted forest areas, which would fail to set up that local circulation which is brought about by differences in temperature and permits an exchange of the forest climate to the neighboring field.

INFLUENCE OF FORESTS UPON WATER AND SOIL CONDITIONS.

(1) In consequence of deforestation evaporation from the soil is augmented and accelerated, resulting in unfavorable conditions of soil humidity and affecting unfavorably the size and continuity of springs. The influence of forest cover upon the flow of springs is due to this reduced evaporation as well as to the fact that by the protecting forest cover the soil is kept granular and allows more water to penetrate and percolate than would otherwise. In this connection, however, it is the condition of the forest floor that is of greatest importance. Where the litter and humus mold is burned up, as in many if not most of our mountain forests, this favorable influence is largely destroyed although the trees are still standing. (Pp. 130–137.)

(2) Snow is held longer in the forest and its melting is retarded, giving longer time for filtration into the ground, which also being frozen to lesser depth is more apt to be open for subterranean drainage. Altogether forest conditions favor in general larger subterranean and less surface drainage, yet the moss or litter of the forest floor retains a large part of the precipitation and prevents its filtration to the soil, and thus may diminish the supply to springs. This is especially possible with small precipitations. Of copious rains and large amounts of snow water, quantities, greater or less, penetrate the soil, and according to its nature into lower strata and to springs. This drainage is facilitated not only by the numerous channels furnished by dead and living roots, but also by the influence of the forest cover in preserving the loose and porous structure of the soil.

Although the quantity of water offered for drainage on naked soil is larger, and although a large quantity is utilized by the trees in the process of growth, yet the influence of the soil cover in retarding evaporation is liable to offset this loss, as the soil cover is not itself dried out.

The forest, then, even if under unfavorable topographical and soil conditions (steep slopes and impermeable soils) it may not permit larger quantities of water to drain off underground and in springs, can yet influence their constancy and equable flow by preventing loss from evaporation. (Pp. 137–140.)

(3) The surface drainage is retarded by the uneven forest floor more than by any other kind of soil cover. Small precipitations are apt to be prevented from running off superficially through absorption by the forest floor. In case of heavy rainfalls this mechanical retardation in connection with greater subterranean drainage may reduce the danger from freshets by preventing the rapid collection into runs. Yet, in regions with steep declivities and impermeable soil such rains may be shed superficially and produce freshets in spite of the forest floor, and an effect upon water conditions can exist only from the following consideration. (Pp. 140–159.)

(4) The well-kept forest floor, better than even the close sod of a meadow, prevents erosion and abrasion of the soil and the washing of soil and detritus into brooks and rivers.

This erosion is especially detrimental to agricultural interests as well as water flow in regions with this surface and impenetrable subsoils, and where rains are apt to be explosive in their occurrence, as in our western and southern country. The best soil of the farms is often washed into the rivers, and the water stages of the latter by the accumulations of this soil are influenced unfavorably. (Pp. 159–162.)

(5) Water stages in rivers and streams which move outside the mountain valleys are dependent upon such a complication of climatic, topographic, geological, and geographical conditions at the headwaters of their affluents that they withdraw themselves from a direct correlation to surface conditions alone. Yet it stands to reason that the conditions at the headwaters of each affluent must ultimately be reflected in the flow of the main river. The temporary retention of large amounts of water and eventual change into subterranean drainage which the well-kept forest floor produces, the consequent lengthening in the time of flow, and especially the prevention of accumulation and carrying of soil and detritus which are deposited in the river and change its bed, would at least tend to alleviate the dangers from abnormal floods and reduce the number and height of regular floods. (Pp. 162–170.)

SANITARY INFLUENCE OF FORESTS.

(1) The claimed influence of greater purity of the air due to greater oxygen and ozone production does not seem to be significant. (P. 171.)

(2) The protection against sun and wind and consequent absence of extreme conditions may be considered favorable. (P. 171.)

(3) The soil conditions of the forest are unfavorable to the production and existence of pathogenic microbes, especially those of the cholera and yellow fever, and the comparative absence of wind and dust, in which such microbes are carried into the air, may be considered as the principal claim for the hygienic significance of the forest. (P. 172.)

We may summarize that the position of the forest as a climatic factor is still uncertain, at least as to its practical and quantitative importance, but that its relation to water and soil conditions is well established. As a climatic factor it would appear that the forest of the plain is of more importance than that of the mountains, where the more potent influence of elevation obscures and reduces in significance the influence of their cover; as a regulator of water conditions the forest of the mountains is the important factor; and since this influence makes itself felt far distant from the location of the forest, the claim for attention of Government activity and for statesmanlike policy with reference to this factor of national welfare may be considered as well founded. Every civilized government must in time own or control the forest cover of the mountains in order to secure desirable water conditions.

In conclusion I may urge that systematic observations bearing on the subject of forest influences should be instituted in this country by a Government agency, perhaps under the authority of the Weather Bureau and with the cooperation of the agricultural experiment stations. No other country is so well adapted for the study of this question as the United States, offering all the varying climatic conditions of a whole continent under one government, with changes in forest conditions constantly progressing.

II.—REVIEW OF FOREST METEOROLOGICAL OBSERVATIONS: A STUDY PRELIMINARY TO THE DISCUSSION OF THE RELATION OF FORESTS TO CLIMATE.

By M. W. Harrington.

THE NATURE OF THE PROBLEM.

The covering of the earth's surface determines many of the minor features of climate, and especially those features which are of importance for agriculture. The insular climate, the coast climate, the desert and prairie climates, the differences between steady winters with continuous snow-covering and variable winters with little or no snow, all have peculiarities that are due to the character of the covering of the earth's surface at or near the station which has the climate in question.

A striking illustration of the effect of the surface-covering on climate and weather is seen in the case of a snow-covering. This has been studied recently by an eminent Russian meteorologist, Dr. Woeikoff, who finds the influence of the snow to be surprisingly far-reaching. It chills and equalizes the temperature; it promotes the passage of blizzards and other winter storms; it retards the spring; it feeds the water more slowly to the streams; it promotes the continuance of clear, dry weather with high barometric pressure; and it has many other effects which are of hardly less importance.

The forest is to be considered, in its effects on climate and weather, as a special form of surface-covering. Its effects are of the same order as those produced by a covering of sand, or sod, or water, but the forest effect has some peculiar features which are due to the fact that the covering is elevated to some extent above the soil. This imparts to the soil in some degree the climatic characteristics due to a topographical elevation, and also causes a series of wind-break effects which are not found with the other forms of surface-covering. On account of this distinctive feature, the problem of forest climatology separates into two problems, which must be considered each by itself. The one relates to the climate of the interior of the forest, the other to the effects of the forest on the climate of the open country around it. The two are quite different; the first is of relatively little importance except as it relates to the second. It is the second which is of interest and importance so far as relates to the suitability of a climate for residence and agriculture.

The solution of these two problems is very much complicated by the variety of conditions of the forest itself. The forest, woods, or woodlands may vary in extent all the way from the Amazon forest, which covers a large part of South America, or the corresponding forests of tropical Africa, to the woodlot of the farm, the grove, or the park. In density of tree-growth they vary quite as widely. The openings in forests are especially subject to forest climatic action, as anyone knows who has found himself in a tropical forest glade at the hottest hour of the day; and these openings vary in form and in size all the way from the forest gallery or swale through the oak openings and little prairies to the regions where the prairies prevail and the forest is reduced to islands of woods or to fringes along the streams. In height the trees range from upward of 300 feet to the low coppice or brush of a few feet elevation; some forests are of fairly uniform height, like the northern forests of firs and spruces, while others are composed of plants of all heights from the herb to the forest giant. This is mostly the case with the tropical forests, where the giants are scattered between high and low trees and open glades,.so arranged that the sunbeams, notwithstanding the density of the vegetation, sift through to the soil itself. In undergrowth, in persistence of leaves, and in quantity of shade there is also every possible variation.

The effect of a mixed forest of deciduous trees must differ from that of an evergreen forest with needle-shaped leaves, and this again from forests of such trees as flourish in Australia, New Holland, and elsewhere, whose leaves stand more vertically, so that the shade bears little relation to the leafiness. Such trees are found in many parts of the world; our own Kentucky coffee tree is of this sort, and the lack of shade under a tree of this kind in full leaf in July is always a surprise.

Again, the litter accumulating in the forest has an important influence on its action, and the effects of the forest must be also much modified by many factors which determine its condition, but are not strictly a part of it, such as the soil on which it grows, the abundance or scarcity of water, the slope of the land, the altitude above sea level, the latitude, and the prevailing degree of cloudiness. Any of these peculiarities may sensibly modify not only the climate of the interior of the forest but also the influence which the forest may exert on the climate of adjacent territory.

The literature of forest meteorology is already a large one. Löffelholz-Colberg published in 1872 a catalogue of the publications on the significance and importance of the forest, and since the issue of that catalogue the literature of the subject has grown at a rapid rate. Nearly all the publications to which he refers bear on the meteorological aspects of the forest. The longer bibliographical references given by him number 190, and there are briefer references to very many more. Löffelholz-Colberg's list begins with Fernando Columbus, the son of Christopher Columbus, who attributes the heavy rainfull on Jamaica to its wealth of forests, and the decrease of rain on the Azores and Canaries to the removal of their forests. In the sixteenth and seventeenth centuries the subject was already attracting the attention of the French Government, and in fact governmental interest in the subject goes back to the time of the immediate successors of Charlemagne. It is interesting to read over the abstracts of opinions which are recorded in Löffelholz-Colberg's small book. Every variety of opinion can be found there, from those which attribute to the forest about everything which is desirable in climate and even endow it with a powerful influence on morals, to those who believe it is entirely without influence, and from those who think that its influence does not extend beyond its own margin, to those who would attribute the deterioration of the climate of the Old World to the removal of the forests of the New. The reasons for this extraordinary variation in opinion are to be found in the method employed for solving the problems of forest meteorology. Leaving out of account the solutions which were purely sentimental or purely touristic, the conclusions were generally founded on what may be called the historical method. This consists in finding a country which has been once wooded, but from which the forests have been removed, or one which was once open, but later became wooded. The climate at the beginning and end of the time involved is then ascertained or assumed, and the changes in the climate are attributed to the change in the forest cover. The unçertainties of this method are so great as to make it generally useless. It is seldom possible to be sure of the early forest condition of the country in question. For this purpose reliance must generally be placed on incidental references by the earlier writers, and these are usually ambiguous and uncertain. Even where the change in forest conditions can be proved beyond the possibility of doubt, the character of the early climate can not be ascertained with a sufficient degree of accuracy. If the period in question preceded the introduction of meteorological instruments, then the character of the climate must be judged by the nature of the crops raised or from facts of a similar nature given by earlier writers. If observations were taken they were generally rude and by means of imperfect instruments; their errors would probably approach in magnitude the quantity of forest influence which is to be determined. Besides, the fixing of the data of climate with our modern exact instruments and better methods requires observations for a long series of years. The variations of the elements of climate (the temperature, humidity, rainfall, winds, and cloudiness) are great from day to day and from year to year, and it takes numerous observations, scattered through many years and taken on a uniform system, to give fixed values for the climate. The rainfall for two successive years on the same spot might differ by several times as much as the difference which could be reasonably expected between that on prairie and on forest. In addition to this, there is no certainty, generally, that any change of climate which is satisfactorily proven is necessarily due to a change in the forest. Changes are constantly going on in the climate of all stations and entirely without obvious connection with surrounding forest conditions. In fact, their causes are beyond our present knowledge.

These are the secular changes, so called; they are probably periodic, and their periods may be tens, scores, or hundreds of years. It is hardly possible to find a long series of observations in which traces of these secular changes are not evident.

The historical method has really given but meager results of a reliable character. On the other hand, the extravagant results to which it has sometimes led have cast discredit on the whole subject of the influence of forests on climate. It will not be used in what follows except in a single case, in which all the conditions which can reasonably be required seem to be fairly fulfilled.

There are also recognized results of forest action which are entirely distinct from the meteorological influences with which we are here concerned and which refer to soil and water conditions. Such is the influence of forests on the flow of surface water and the occurrence of floods, on the amount of ground water and the preservation of springs, on the holding of movable soils or reclaiming of swampy ones. These are all of the highest importance, but they will not be consi[illegible]. The questions of temperature and of the changes of the[illegible] only ones belonging to forest meteorology proper.

SYSTEMATIC OBSERVATIONS IN FOREST METEOROLOGY.

There are several series of sporadic observations on forest meteorology made before the beginning of this century, as, for instance, Hunter's observations on the temperature of trees in 1775 and 1778, and Schaepff's observations on the same subject in New York in 1783. The first systematic observations seem to be those taken at Geneva from 1796 to 1800 by Pictet and Maurice. They referred to tree temperatures and were made on a horse-chestnut tree two feet in diameter.

The thermometer was placed in a hole in the north side of the trunk six inches deep, and the space around the stem was closed up with wax, so that the water and air from the outside would not influence the temperature shown by the instrument. The observations were made without interruption at sunrise, 2 o'clock p. m., and sunset. Comparative observations were made at the same time on a thermometer to the north, in the shade, and on four ground thermometers at depths of 3 inches, 1 foot 5 inches, 4 feet 3 inches, and 12 feet 8 inches. The observations were made with precautions similar to those now considered necessary, but not generally practiced at that time.

Kaemtz carried on a good many scattered but instructive forest and agricultural observations before the publication of his meteorology in 1831–'34. In 1839–'40, Bravais at Bossekop, and Thomas at Kaaford, both in Lapland, took a long series of winter tree temperatures. Bravais put the bulb of a mercurial theremometer in the heart of a living pine which was 6 inches in diameter. Thomas compared the temperature of two large pines close together, one dead and the other living. The latter showed a slightly higher temperature than the former.

In the winter of 1857–'58, Bourgeau carried on a series of tree temperature observations at Fort Carlton, on the Saskatchewan River, latitude about 50°.

FRANCE.

The beginning, however, of systematic observations on the short-range forest meteorological problem of the relative condition of the air in and about forests and the incitement to the modern activity in this direction seem to have come from the observations of M. A. C. Becquerel and his son Edmund, which began at Chatillon-sur-Loing, about 70 miles south of Paris, on July 30, 1858. These observations, now relating to forest meteorology, now to some other branch of the science, now carried on at Chatillon or its vicinity, now at Paris in the Jardin des Plantes, and generally with the aid of the French Academy of Sciences, have been conducted by MM. Becquerel and his son from that [illegible] to a quite recent date, and are probably still continued.

[illegible] memoirs and briefer communications which have been made to the academy, based on these observations, form a large and highly instructive addition to knowledge in this science, and they have been [illegible]antly drawn on by subsequent writers. It is in some respects an advantage, in others a disadvantage, that the Messrs. Becquerel have used a special form of instrument in their observations and have followed independent methods. The disadvantage lies in the fact that this makes the observations not strictly comparable with those taken at regular forest meteorological stations, and when the question is one of relatively small differences, as that of temperatures and rainfall within and without forests, this lack of comparability is a serious drawback. On the other hand, there is a great advantage in getting results by different methods and with different instruments, for it serves to get rid of errors that depend on the method. Conclusions drawn from two entirely different sorts of observations are worthy of more confidence than those drawn from two sets taken in the same way.

The observations of the Messrs. Becquerel were taken with electric thermometers. They depend on thermo-electric principles, and the elder Becquerel had published studies on them as early as 1826, and afterwards used them in determining the temperature of the different envelopes of flames. The instrument as used was composed of a closed circuit a part of which was of copper and a part of iron. The two are soldered at the ends, and a galvanometer is introduced into the circuit. By the principles of thermo-electricity whenever the two soldered ends are at the same temperature, there is no current and the galvanometer is not affected. If one of the junctions is warmer than the other, then a current is produced in the one or other direction, and the needle of the galvanometer swings to the corresponding side. If now one junction is placed in the medium the heat of which is to be measured, and the other is left accessible and is warmed or cooled until the needle stands at zero, the temperature of the latter junction is the same as that of the former. One junction can be placed in a flame, or in an animal or plant, or at the top of a tree, or at a depth in the ground, and its temperature can be ascertained by manipulating the other.

This method requires many precautions, and can not be conveniently used for maximum and minimum temperatures, but in competent hands it is very serviceable and is capable of minute accuracy.

In the observations of the Messrs. Becquerel it was so arranged that a change of one degree of temperature would cause a deflection of ten degrees in the needle. The needle was brought to zero with the aid of a lens, and an accuracy of reading to a tenth of a degree centigrade in the galvanometer was abundantly assured. Every precaution was taken. For instance, a junction exposed to the rays of the sun was covered with a triple reflector which screened from the sun's rays, but permitted free ventilation. The results have every guarantee of accuracy and are worthy of unusual confidence.

M. Becquerel's first memoir relating to the forest meteorological problems was not published until 1864. Meantime other students of the subject were showing signs of activity. The French forest inspectors Contegril and Bellot took many observations in 1859 and 1860 on the disposal of rainfall in woods as compared with that in open fields, and similar observations were taken in southern France. Hofmann at Giessen and Baur at Hohenheim had been taking forest observations for some time. In 1862 and 1863, Krutzsch, in Saxony, established nine forest stations; several were established in Bavaria, and Count Berchem-Hainhausen, in his private capacity as a large landowner, supported two in Bohemia. In 1866–68, in Posen, Rivoli, also a private landowner, made many simultaneous comparative observations in forests and fields, including temperature, humidity, and evaporation. His observations on individual features of forest action were confined to the season at which they were greatest. The fertile idea in modern forest meteorological observations consists in having comparative stations at which observations are taken simultaneously. These stations must be as nearly as possible alike, except that one is to be in the woods, the other outside. This happy idea, already employed by Becquerel and Rivoli, and doubtless by others, but not by all, was first put to systematic use under governmental auspices at stations near Nancy. The French forest administration undertook to set at rest the questions of forest influence on climate, and to this end instructed the school of forestry at Nancy to undertake the necessary studies. In April, 1886, observations were commenced by Prof. Mathieu, of Nancy, with the view of determining the influence which a wooded or unwooded country has upon the moisture received from the air. Three stations were selected; they were described by Dr. Hough in his report for 1877,* page 262. The most interesting feature about them is the forest rain gauge at Cinq-Franchées. It was made to cover exactly the surface covered by the tree top and was placed with the tree in the center, careful arrangements having been made to direct into the gauge all water which ran down the tree. In 1870 a fourth station was added, that of the agricultural station of the school. The altitude of this station is 712 feet, somewhat less than the others.

In February, 1874, forest observations were undertaken by MM. Fautrat and Sartiaux, and continued by the first. The stations were in the department of Oise, a few miles north of Paris. This is a rolling territory of no great elevations or irregularities, and the southern part, containing the better-known forest of Compiegne, is well wooded and somewhat swampy. One pair of stations was in the state forest of Halatte, about a cluster of oaks and hornbeams of twenty or thirty years. The forest itself is large, containing about twelve thousand acres. M. Fautrat had the happy idea of trying some observations above the forest. His stations were therefore duplicated, one being below at the height of 4½ feet (1.37 m.), the other above the trees about 20 feet (6.09 m.), and 46 feet (14.02 m.) above the ground. The forest station was reproduced 1,000 feet (304.8 m.) away in the open fields. Each station had thermometers, psychrometers, rain gauges, and evaporometer. Under the trees the number of rain gauges was increased to six, distributed in such a way as to give a good indication of the amount of rain passing through the foliage. The stations were on a soil of fine sand, cemented by clay, and were at an elevation of 354 feet (107.9 m.) (base) above the sea and 400 feet (121.9 m.) taken above the trees. About 5 miles (8.04674 kil.) away was a second pair of double stations; they were in and near the state forest of Ermenonville. The trees were twenty-five year pines, about 40 feet (12.19m.) high. The stations at Halatte were duplicated here, including the elevation of the station above the trees. This brought the higher instruments to within a very short distance of the foliage—5 or 6 feet. The soil here was a coarse, white sand, and the open-field station was on a sandy plain. The elevations above the sea were 302 (92.05 m.) and 341 (103.9 m.) feet. There were six ordinary gauges under the trees and an additional large one, over 5 feet (1.52 m.) in diameter, which surrounded the trunk of a large pine tree. The printed observations (in the *Comptes rendus*) are somewhat fragmentary and extend over about four years. There has

---

* Report on Forestry, vol. I, United States Department of Agriculture

Swedish stations for forest meteorology.

Station.	Character.	Latitude.	Longitude, east.	Altitude.	Situation.	Soil.	Distance to woods.	Kinds of trees.
		° ′	° ′	*Feet.*			*Feet.*	
Tierp	Open	60 17	17 28	121	In village	Clay and sand.	9,000	
Tobo	Glade	60 15	17 40	121	Marshy forest land	Clay	100	40-year pines and firs.
Dalboda	Forest	60 7	17 33	164	Marshy, near small lake	Sandy	....	80-year pines and firs.
Do	Glade	60 7	17 33	164	....do	...do.	600	
Akerlänna	...do	60 1	17 23	164	Marshy forest land	...do	160	40-year pines and firs.
Bälinge	Open	59 57	17 32	92	Great plain of Upsala	Clay	4,000	
Upsala	...do	59 52	17 38	79	Hill; small groves about	...do	5,000	
Rekasta	...do	59 41	17 4	69	Cultivated	...do	1,600	
Alderstugan	Forest	59 41	16 17	200	Marshy forest land	Gravelly	....	60-year firs.
Do	Glade	59 41	16 17	200	....do	Loam	360	60-year pines and birches.
Lillhärad	Open	59 39	16 23	98	Large plain	Hard clay	4,000	
Äugsvallen	Glade	59 38	17 12	69	In large forest	Loam	300	30–60-year pines and firs
Signalsburg	...do	59 38	17 19	66	Wooded, rough region	Gravel	200	30–50-year pines and firs.
Dingtuna	Open	59 34	16 24	39	Cultivated	Clay	300	
Sparhult	Forest	58 35	13 40	459	Wooded region	Sandy	....	70-year firs.
Do	Glade	58 35	13 40	459	....do	...do	230	30-year firs.
Osterplana	Open	58 35	13 26	574	Treeless terrace	....	....	
Helde	...do	58 34	13 30	230	Cultivated	....	2,300	
Danielslund	Forest	56 15	12 52	33	....	....	....	
Skorpinge	...do	56 14	12 51	33	....	....	....	

The stations mentioned so far were generally parallel stations, that is double, one set of instruments being in the woods, the other outside.

AUSTRIA.

The radial stations proposed by Dr. Lorenz-Liburnau were established in Austria in 1884 and following years. The outside stations in each radial system were to be in various directions and at varying distances from the stations in the forest.

Dr. Liburnau found great difficulty in arranging them, since some of the stations should be at considerable distances, and all of the same group should be at the same sea level. Naturally the arrangement would also require a separate and distinct forest of no great extent. These conditions were hard to fill and but few suitable places were found in the whole Austrian Empire. Up to the present time only three such groups of stations have been established:

(1) In northeastern Austria, the group about Karlslust on an extended plateau, between Retz and Znaim, with an average elevation of 1,300 feet (396 m.).

(2) In eastern Galicia, near the Russian boundary, on an extensive plateau, between Konstancya and Skala, with an average elevation of 886 feet (270 m.).

(3) On the northern base of the Carpathians, in the undulating region near Rachin, at an elevation of 1,300 (396 m.) to 1,600 feet (487.6 m.).

Observations of temperature and humidity were taken under the trees, also in the tree crowns and at various elevations above the trees. Corresponding observations at the same heights were made over open land.

The results of the observations during the years 1885 to 1887 so far published have not been before the writer.* From a review, however, it is learned that the director, Dr. Liburnau, a most competent authority, draws the following conclusions:

> (*a*) The normal decrease of temperature with the elevation, observed in the open country, is modified in the forest, during the day, by the warming of the crown cover, especially of the upper portions. In the forest the crown cover has the same relation to the temperature as have the soil and the smaller vegetation in the open country. Thus the normal decrease of temperature with the elevation remains uniform in the open country, but is more modified in the forest under the influence of the warmed crown-cover than in the open country under the influence of the soil.
>
> (*b*) During the night the crown cover has also the same relationship to the soil and vegetation of the open country, except that temperature reductions have different values.
>
> (*c*) As the temperature in the forest is higher in the upper regions of the crown cover than in the lower and among the trunks and on the ground, especially during the day, it follows that the shade contributes more to its reduction of temperature

---

*Investigations into the humidity and condition of temperature of the forest and of the open country, and the results of the forest influence upon the climate in its proximity.

than transpiration; altogether, the cooling effect of transpiration up to this time seems to have been overestimated.

(*d*) The warming effect of the upper crown cover upon the temperature during the day in a beech growth extends only about 2 m. (6½ feet) above the crowns, and indeed is most pronounced in the warmest months.

(*e*) The absolute values of the temperature differences effected by the forest are not very important, but depend to a great extent upon the species of the trees on the one hand and the kind of soil cover of the open country on the other.

(*f*) It is remarkable that in the forest the relative humidity increases and decreases with the absolute humidity, whereas it is known that in general, and also at the station in the open country, these two climatic elements are inverse. This is accounted for by the fact that the forest is a source of atmospheric aqueous vapor as well as of cooling.

(*g*) The results of the investigations at Ried show that the aqueous vapors from the forest often affect the air to a great height. With this increase in the humidity of the atmosphere the chances of precipitation are increased.

From these observations Dr. Liburnau draws the following conclusions regarding the influence of forests upon the general climate of the region in its vicinity:

(*h*) Since the temperature in the forest, to above the crown-cover, is in most cases lower than it is below in the open country, it follows that modifying currents can arise from the forest at any time of the day, especially in a generally still atmosphere. In summer, during the night and toward morning, differences of temperature can produce a current of cool air from the forest and from the air strata immediately above the forest; in the warmer part of the day, however, such currents can be looked for only from below and in the crown cover.

(*i*) In the summer half of the year, winds coming from a distance and crossing a forest can be cooled below their original temperature by the influence of the forest considerably in the night and toward morning, but less during the day.

(*j*) The conclusions which Dr. Liburnau arrives at concerning atmospheric humidity are based for the most part on the results of the observations at Ried. It was established that winds from the forest (at least from a beech forest) convey a greater water supply into the neighboring open country. It depends, however, upon the original humidity of winds crossing a forest and upon the distribution of temperature whether or not their humidity will be increased and they will subsequently increase the humidity of the adjacent open country.

Hence Dr. Liburnau concludes that the humidity of warm and dry winds will be increased by the presence of a forest, but that such winds as are already quite thoroughly saturated can receive no essential addition of aqueous vapor, but only an increase in relative humidity. It is also observed at Ried that winds coming from the forest to the station in the open country have a higher humidity, both absolute and relative.

(*k*) Finally, Dr. Liburnau remarks with reference to the distant influence (of the forest) that this absolute humidity, as increased by the effect of the forest,* remains in the atmosphere as long as it is not lost by condensation, and that on the other hand, the increased relative humidity decreases as soon as the forest air reaches the warmer open country.

---

*Within the last two months a further contribution from these stations has been published, discussing more in detail the influence of forest areas on the climatic condition of the neighborhood, which publication, unfortunately, could not be obtained in time for a review in this report. B. E. F.

OBJECTS AND METHODS.

In 1868, before the publication of Ebermayer's results or those of any other systematic series of co-operative observations in forest meteorology, the Congress of German Foresters and Farmers at Vienna, struck with the paucity of results from the much talked of forest meteorological observations, put the subject in the hands of a special committee composed of the most eminent German students and authorities on the subject. The committee met at Regensburg in November. Its attention was chiefly directed to other aspects of the forestry question, but it proposed a sort of programme or series of problems as the proper object of forest meteorological observations. These are:

(1) Determination of the temperature under woods and outside.

(2) Investigation of the temperature of trees as compared with that of the soil and air.

(3) Investigation of the soil of forests, determination of its temperature at different depths, situations, exposure, and under different kinds of trees.

(4) Influence of the covering of the soil on damage by frost.

(5) Determination of rainfall under woods and outside.

(6) Influence of the covering on the humidity of the soil and on the evaporation from it.

(7) Determination of the amount of evaporation in the forest and without.

(8) Determination of the ground water at different depths, under woods and outside, with various aspects and under various kinds of trees.

(9) Determination of the amount of carbonic acid and of the humidity of the forest during the season of vegetation, under a more or less compact cover of foliage, under different trees and in varied situations.

This is an extensive programme, and is of interest as the first which had been formulated under such auspices. It will be noticed, however, that it does not include observations at any elevation, and especially observations above the woods. It does not seem to have occurred to the committee that meteorologically the forest is a sort of surface covering to be compared with that of sod or crops, sand or water, and that in other cases observations are taken as well above the surface covering as in it or below it. Observations above woods were, however, not included by the committee, and since this programme served to give object and aim to the new services of that day, as well as to those established later, these important observations have been almost entirely neglected.

The Prussian (afterwards the German) forest meteorological service, established six years later, adhered, in most points, to the Regensburg programme. In its instructions to its observers it defines their task as that of furnishing observations on—

(1) The temperature of the air in forests compared with that in open fields.

(2) The temperature of the air at 5 feet elevation, compared with that in the tree crown.

(3) The hygrometric condition of the air within and without woods.

(4) The same at a height of 5 feet compared with that in the tree crown.

(5) Evaporation within and without the woods.

(6) The rain and snow reaching the ground within and without the woods.

(7) The temperatures of forest soil at the surface and at the depths of 6 inches, 1, 2, 3, and 4 feet, compared with the temperatures at corresponding depths in the open fields.

There were also the highly important conditions attached that the instruments and their disposition should be alike, and that the hours of observation and methods of reduction should be the same.

In the second international meteorological congress, held at Rome in April, 1879, it was resolved that—

> In order to contribute to the progress of forest and agricultural meteorology, the congress recommends as a programme of study:
>
> (1) The influence of the meteorological elements upon vegetation.
>
> (2) The inverse influence of vegetation upon the meteorological elements.
>
> (3) Agricultural warnings.

The congress, finding the subject too important to treat hastily, concluded to charge the international committee with the convening of a special international conference to take into consideration the development of agricultural and forest meteorology.

Such a conference convened at Vienna on the 6th of September, 1880. This was so representative a meeting and illustrated so well what the most able and most experienced men thought on this subject that the reports, remarks, and resolutions will be given at some length so far as they relate to the action of forests on climate. Dr. Lorenz-Liburnau, of the Austrian Department of Agriculture, and president of the conference, said that when the influence of vegetation on climate was referred to, solitary plants could not be meant. It was a question of masses of vegetation, such as meadows, moors, and forests. There was also a distinction to be made between the climatic action produced within the massed vegetation and that upon the vicinity. It is only for a forest that the question of the interior climatic action can arise, and on this question certain definite numerical results had been obtained for central Europe, in certain localities. These show that the inner temperatures are slightly lowered, the temperature extremes are moderated, the relative humidity is raised, and the evaporation diminished, while it remains doubtful whether the absolute humidity or the frequency or quantity of precipitation are changed.

As to the influence of vegetation on its vicinity, exact data do not exist, either for the forest or for other forms of vegetation in mass. Yet, on theoretical grounds, it can not be doubted that such an influence exists, within certain limits, and appropriate methods of observation must be able to show it. They should include observations on the temperature, precipitation, cloudiness, insolation, and wind. The conference adopted these views.

As to the method of observation, Dr. Liburnau pointed out that the existing arrangement of one station within and a station for comparison outside the region covered by the vegetation to be investigated might be called the method of parallel stations. This is a commendable arrangement, and promises the speedier results, the more the climate at the station takes on a continental character. The distance of the stations of each pair from each other is an important point. In each pair the meteorological elements should be taken at the ordinary height and also in the tree crown. The temperature of trees and soil should be included. As to precipitation, it is of importance to get not only the amount which passes through the foliage, but also that which runs down the trunk. The penetration of precipitation into the soil, the evaporation from the surface in different kinds of forests and with different coverings of the soil are of importance because the state of humidity and temperature depends on them. Observations of ozone at different heights are contingently recommended. These observations should be exactly duplicated, so far as possible, at the field stations. The tree-top observations should be duplicated by field observations at the same height. To get the influence of the forests on their vicinity, a different system of stations is desirable; this should be a system of radial stations as contradistinguished from the parallel system. This consists of one station in the forest and several outside, arranged in the directions of the four principal points of the compass. There should be at least two in each direction and at different distances from the forest, so that one set should include at least nine stations. All the observations carried on at the parallel stations should also be taken at the forest station of the radial system, but at the field stations the number of instruments may be reduced to a psychrometer, evaporometer (Piche's), and a rain gauge, and the observations at the height of the tree crown may be omitted.

The question of exposure of thermometers aroused much discussion and it was agreed that comparative observations should be undertaken. As to hours of observation, Dr. Müttrich favored morning and noon (2 p. m.), while M. Grandeau and Dr. Ebermayer favored morning and evening hours. Dr. Riegler thought the 2 p. m. observation was to be especially recommended because it was about the hour of maximum forest effect. The conference finally decided to recommend morning and evening hours, with the reading of maximum and minimum thermomenters. Observations of isolation were discussed, but MM. Mascart and Tacchini assured the conference that no suitable actinometer exists. It was, therefore, decided that observations should at first be undertaken only on the time, duration, and relative intensity of sunshine; the latter on sensitive paper, at stations of the first order. The subject of an actinometer capable of giving insolation temperatures with exactness was recommended as a subject worthy of the especial attention of scientific institutions.

It was decided that soil temperatures should be taken at various depths up to 40 inches (1 mm.) The humidity should be obtained by the means of August's psychrometer and a hair hygrometer, and tridaily observation should be taken. A long discussion followed on Dr. Liburnau's recommendation of Piche's evaporometer. It was stated that the observations gave no means of comparison with actual natural processes, that the readings of the instruments were untrustworthy and the errors hard to correct, that it was desirable to follow more exactly the processes of nature, that it is not possible to find an instrument fulfilling all necessary conditions, and that on this account the Italian service had rejected all evaporometers. The conference finally decided that, while observations of evaporation were important, there is no form of measuring instrument which can be especially recommended. An instrument should be invented which would permit the measurement of evaporation from a free water surface and also from soils of different characters. Provisionally observations should be carried on with the weighing instruments and with Cantoni's modification of Piche's instrument.

Clouds should be observed; fog should be recorded when it covers the station and its density should be given on a predetermined scale. Herr Friesenhoff recommended a measurer of dew depending on the power of rock salt to appropriate atmospheric water. Drs. Neumayer and Ebermayer expressed the opinion that balance drosometers should be tried. They should have larger dimensions (2 feet square or more) which should be filled with different materials. The conference commended the subject of a good measurer of dew as a proper subject of study. The measurer of precipitation should be on the model recommended by the International Congress and Committee. The seepage of ground water is important, but the so-called lysimeter is not to be recommended. Wind observation should be taken, as at ordinary stations.

The system of parallel stations, already adopted in Bavaria, Switzerland, and at the other German stations, was especially commended. Radial stations were commended for the broader fields of observation, and it was recommended that a series of such stations should be established in eastern Germany and in Austria-Hungary, and the final recommendation was made that observations should be made at the forest station of each radial system, directly over the crown of the trees. Thus this happy method, the fundamental importance of which makes it strange that it was not employed from the first, reached at least the stage of recommendation for general use. The practical difficulty of its use is probably what has prevented its adoption. This could be easily overcome by the use of registering instruments which are made to run for fifteen days without attention, or by the use of the now excellent instruments for electric registry at a distance.

To the proposal of the first meteorological congress for replies as to what could best be done, Dr. Woeikoff made a suggestion which was not taken into consideration by the conference. He proposed India as the best field for such studies, especially with reference to rainfall.

For this purpose observations could best be taken in the central provinces and Berar, as they are hottest in April and May and the forests are extensive. India also permits a study of the effects of irrigation on forests.

The German service supplies each of its stations with psychrometer, maximum and minimum thermometers, six soil thermometers, barometer, evaporometer, and rain gauge. The soil thermometers for the surface and the depth of 6 inches are supported by small tripods. The four thermometers for greater depths are in wooden cases, open at the bottom and extending downward only so far that the bulb of the thermometer may remain in contact with the soil at the depth required. The cases are placed together and are open at the top to permit of ready access to the instruments. A cover over the open ends keeps out the water and exterior air currents. The thermometers are taken out for observation, read as quickly as possible, and replaced. The evaporometer is a square receptacle of zinc with a surface of about 2 square feet and a depth of about 5 inches. A measured amount of water is placed in it, and the loss, expressed in thickness of layer evaporated, is noted at the beginning of each month. This instrument is protected from precipitation by a wooden roof, but the air is permitted to have free access. The force and direction of the wind are estimated, the former on the 1 to 4 scale.

The rain gauge has an opening of about 2 square feet (18.58^{dm}) and is placed at a height of 5 feet (1.52^{m}), like the other instruments. The snow gauge has the same opening, but a larger body, to prevent the snow from being blown out.

The observers were intrusted with other observations, especially those relating to the leafing, flowering, and other stages of certain plants, and the list of plants to be observed is given. It includes 26 wild plants, mostly trees and shrubs, and 7 cultivated ones. Observations are required of the arrival and disappearance of a few designated species of birds and insects, and the time of heat of the deer and rabbit. The order in which observations were to be taken, the mode of recording, the methods of reduction, and all other details are minutely given in the instructions to observers, and painstaking care is required throughout.

From 1884 Dr. Lorenz-Liburnau put in operation some of the fertile ideas which he had already suggested. The three systems of radial stations were organized as already described. Dr. Liburnau thought that the general character of the influence of the forest on climate was already determined and that there was now required only the elaboration of details. The radial stations were designed to fix the relations of the forests to the climate of the vicinity with varying direction of wind, and a special series of observations were made to fix the relations of forest humidities and temperatures at various elevations, below, in, and above the tree tops, and to determine their modifications with general changes of the weather.

The most elaborate series of observations of this kind were those taken near Ried, in lower Austria, in 1887 and 1888. They were especially devoted to the problems of humidity, and to obtain thoroughly satisfactory results the ordinary wet and dry bulb thermometer was rejected and an exact chemical method substituted. This consisted in passing a known volume of air through calcium chloride and phosphoric acid and ascertaining by weight the water taken up by the latter. The case containing the chemicals was elevated by means of a pulley on a mast, to the height at which the observation was to be taken, and the air was drawn through it by means of an aspirator below, connected with it by a rubber tube.

The observation occupied an hour and thirty minutes and the temperature was taken at the beginning and end by means of an upsetting thermometer, elevated by means of a pulley to the height required.

The results were very exact for the absolute humidity, less so for the relative. The heights at which the observations were taken were 4 inches (101.6^{mm}), 16 (4.87^{m}), 36 (10.97^{m}), and 51 feet (15.5^{m}). The second was under the tree crown, the third in it, and the fourth was 18 or 20 inches above it. The trees were red beeches, 60 to 70 years old, with a few white beeches and firs. The station itself was in and over the beeches.

SOIL TEMPERATURES.

The soil affords an excellent means of measuring the average temperature effects of the forest. This is due in part to the fact that the temperature of the air is not derived so much from the direct rays of the sun as it is from the heat reflected or radiated from terrestrial objects. These absorb the heat from the sun's rays more readily than does the air and yield it again to the air. The soil serves in another way also to average the effects of forests. The soil is more slowly warmed by the sun than is the air, and the deeper the stratum the more slowly it is warmed. The result is that rapid and passing changes of air temperature do not affect it, or affect it only superficially. It tends to show only the great periodic changes in temperature, and from it we are able to ascertain what influence the forest has on these changes.

The results which follow are always given in terms of the difference of temperature of the soil in woods and in open fields. If we put *W* for woods or forests and *O* for open fields, the data given hereafter* for

---

*NOTE ON THE CONSTRUCTION AND READING OF THE DIAGRAMS IN THIS REVIEW.—The horizontal lines (ordinates) above or below the zero line represent values of amounts, degrees of temperature, inches of precipitation or evaporation, percentages, etc. The vertical lines (abscissæ) represent time, dividing the field into twelve seasonal divisions corresponding to the twelve months of the year, the outer lines both standing for the month of December or commencement of winter. The curve lines are constructed by noting on each monthly line the values found for the month, and then connecting these points by either straight or rounded-off lines.

Unless otherwise noted, the values so plotted are the differences between the read-temperature are always, except where otherwise stated, the values of $W-O$. A positive sign (+) indicates always that the woods are warmer than the fields; a negative sign (−), that the woods are cooler than the fields. The degrees are Fahrenheit and the other units of measure are the usual English ones, unless otherwise stated.

In Fig. 1 are given the mean annual differences of temperature for fields and woods at the surface and at depths of 6 inches and 4 feet. These are for the German stations, a brief description of which may be found on page 30. They are arranged in the order of their differences at the surface, and at the right hand are given the average values. It will be noted at once that the differences vary much for the different stations. The mean annual difference for Hadersleben is less than one degree at the surface, while that at Melkerei or Neumath is nearly four degrees. It will also be noticed that the differences at 6 inches vary with respect to each other and also with respect to those at the surface. They are generally less than the surface differences at the same stations, but Hollerath furnishes a notable exception. On the whole they run with the surface differences, but are somewhat less. Again the differences at the depth of 4 feet differ among themselves, but not so much as do the others. Their relative uniformity is due to the depth at which the temperatures are taken, the smaller surface changes, in temperature and in water contents, being little felt. These differences are usually greater than those at the depth of 6 inches and less than those at the surface. But there are exceptions to this, notably in the cases of Hollerath and St. Johann. These differences in the action of the forest are due to several possible causes, such as differences in soil as well in the field as in the forest station, in kind of trees, in their density, in the exposure, in the character of the air drainage.

---

ings under two sets of conditions, namely, in most cases the values which were found for the stations in the woods (W) diminished by the values found for the stations in the open field (O), or $W-O$.

The value of this difference is positive, if the curve runs above the zero line—that is to say, the records for the woods (W) showed higher values than that for the open field (O); it is negative, *i. e.*, the record for the woods was lower, if the curve line runs below the zero line. The greater, therefore, the vertical distance of any point in the curve from zero line, the greater is the influence of the woods. In temperature readings, for instance, the curve above the zero line would denote that the woods were warmer; below the zero line, that the woods were cooler than the open field by as many degrees as the curve runs above or below the zero line, the latter representing that state of conditions when $W=O$, *i. e.*, when there is no difference in the readings for the two sets of conditions.

Where values for each set of conditions are plotted separately, the area included within the two curve lines (hatched) exhibits the difference between the woods and open field.

To exhibit more readily the amount of influence of the forest, the areas included by the zero line and the curve for mean values is also hatched in most cases.

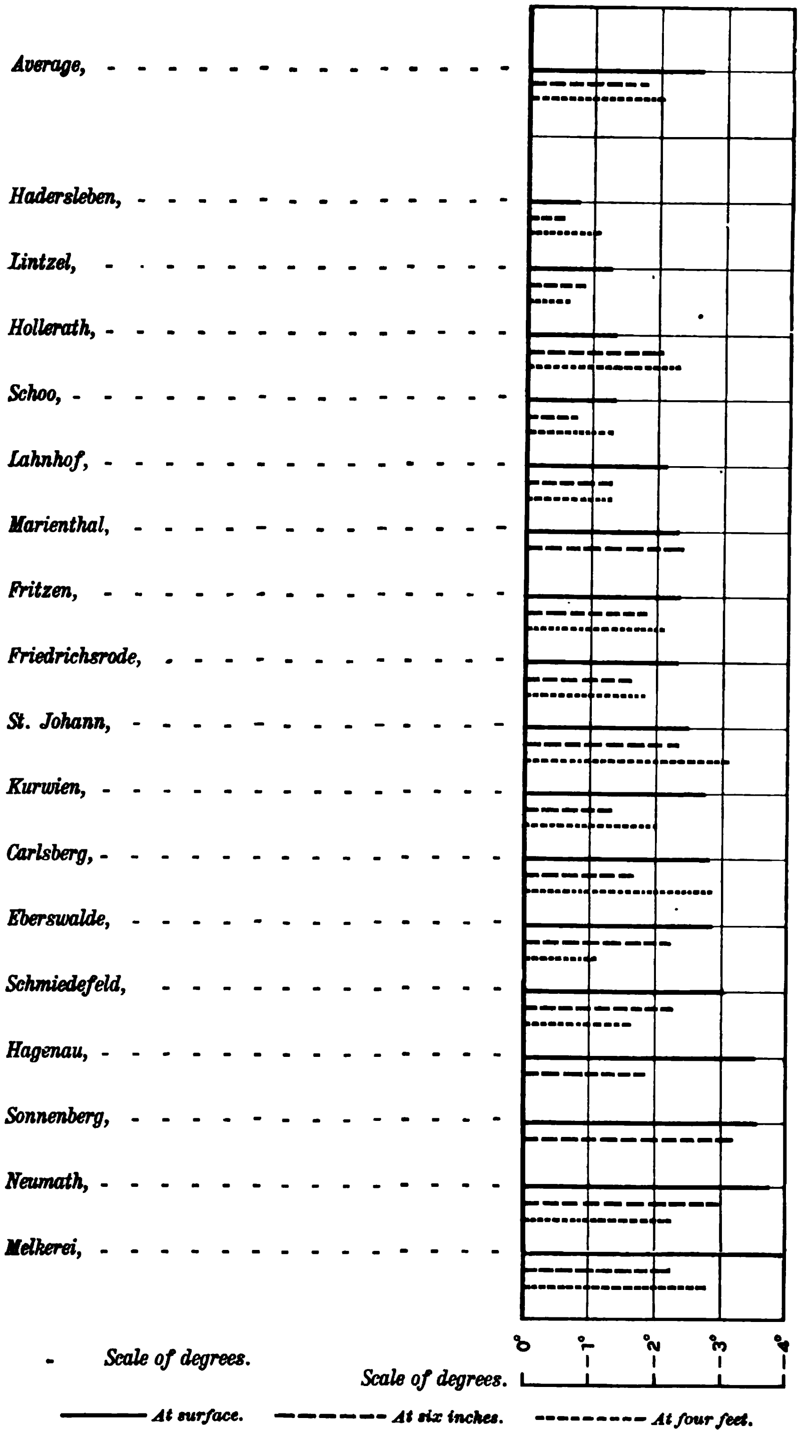


FIG. 1.—Differences of mean annual temperatures of soil (W—O).

Some of these will be discussed later; the material on hand does not permit the discussion of the others. They are instructive, however, in showing how great is the difference in action of different forests. For instance, the effect on the temperature of the surface at Melkerei (−3°.95) is nearly five times as great as at Hadersleben (−0°.84). This difference of action of the forest is far-reaching, for it extends through a layer of 4 feet of badly conducting soil. The difference at this depth at St. Johann (−3°.03) is about three times that at Eberswalde (−1°.06) or at Hadersleben (—1°.04), and is five times that in the young forest at Lintzel (−0°.58). The average of the seventeen stations (representing about two hundred years of observation) should give us good and significant results. It shows for the surface −2°.59, for a depth of 6 inches (152 mm.) −1°.87, and for a depth of 4 feet (1.22 m.) −2°.02. The influence of the forest on the soil, then, is a cooling one, on the average, and for central Europe the cooling amounts to about two and a half degrees for the surface. The cooling is due to several causes: The first is the shade; the foliage, trunks, branches, and twigs cut off much of the sun's heat, absorb and utilize it in vegetative processes, or in evaporation, or reflect it away into space. Thus the surface soil in the forest receives less heat than the surface of the fields. The same screen acts, however, in the reverse direction by preventing radiation to the sky, thus retaining more of the heat than do the open fields. The balance of these two processes, it seems from observation, is in favor of the first and the average result is a cooling one.

But the thatch of living foliage is not the only screen possessed by the forest soil. It has in addition the screen of the forest litter, and this is in a condition to be even more effective than that of living foliage. It lies in contact with the ground, preventing the dissipation of the heat of the soil by moving air, and at the same time lying so loosely as to form air spaces, which act as insulators in the way of preventing the exchange of heat between the forest soil and air. These cooling influences are enforced by the moist condition of the forest soils. It does not warm so easily as the drier field soil, and more of the heat which reaches it is used in evaporative processes than in that of drier soil. The balance of all these processes is, it appears, in the direction of cooling. And the cooler forest soil will cool, to some degree, the air in contact with it, and this air, flowing off to some other place, will take this cooler temperature with it, so that the coolness of the forest soil will make itself felt over the vicinity.

The differences of temperature at the depth of 6 inches (152 mm.) are more than half a degree less than at the surface. In this is to be seen the specific effect of the forest litter; it adds a covering to that possessed by the surface, so that while the deeper layer is cooled as much by the protection from the sun's rays as is the surface, it is not cooled so much by radiation of heat to the sky. Its temperature is, consequently, relatively higher, and it approximates somewhat more the field temperatures.

It is not so easy to explain why the difference at 4 feet averages a little less than at the surface and a little more than at 6 inches. It may be due to retardation in the penetration of diurnal temperatures into the soil. This may be slower in the cool, moist forest soil than in the warmer and drier soil of open fields. If this is the case observations at the same instant at the two stations would determine the temperature at two different parts of their curves. The diurnal changes probably extend to a greater depth than 4 feet, and if they have different times of maxima and minima (later in the forest) the increase of the difference at this depth could be explained. It may be that a part (undoubtedly a small one) of the differences at the surface and at 6 inches may be due to this. The observations were taken at 8 a. m. and 2 p. m.

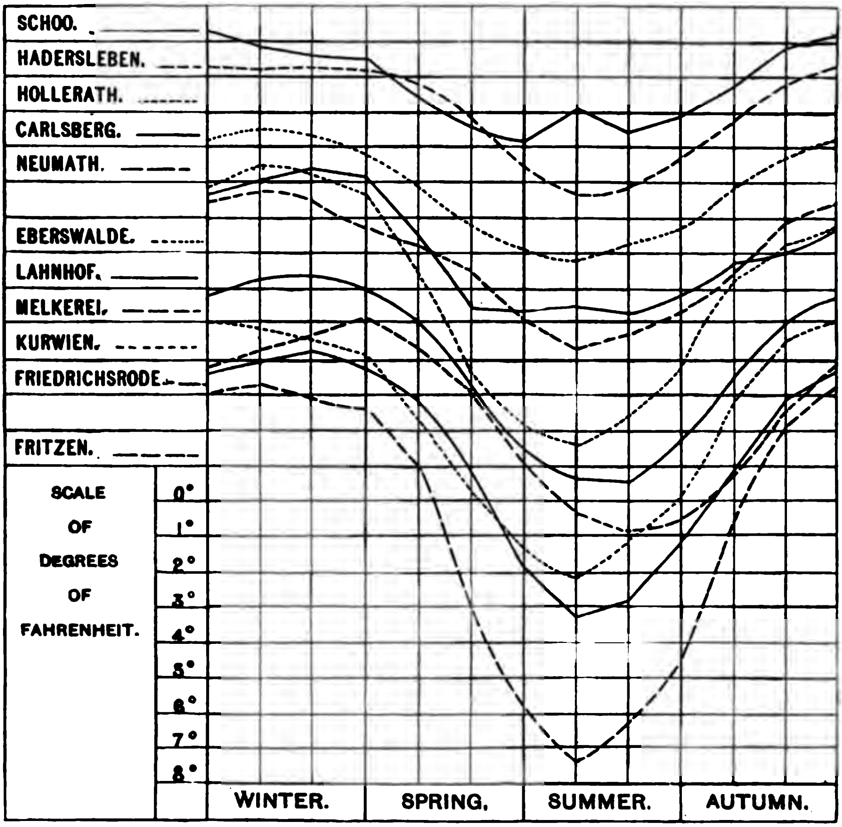


FIG. 2.—Difference of temperature (*W—O*) at the depth of 4 feet. (The line running under the name of a station is its zero line. The curve for the station is represented by the nearest broken, unbroken, or dotted line like that in the margin.)

Turning now to the progress of the difference, "Woods" minus "Open field" readings, through the seasons, or, as we shall generally express it, *W—O*, as shown by the differences of the monthly means, another series of interesting facts appear.

Fig. 2 shows the differences of temperature through the year at the depth of 4 feet. The curves for all the stations for which good monthly means for all the months could be obtained are put on one sheet for comparison. In order not to crowd them too much they are placed at different levels, the zero level for each station being represented by the line running under the name of the station, and the curves belonging to each station either unbroken, broken, or dotted lines nearest to its zero line. Seasonal lines are drawn for the monthly values, winter beginning with December, spring with March, summer with June, and autumn with September. The stations are arranged in the order of the greatest summer differences.

The distances between the horizontal lines representing degrees Fahrenheit, the absolue amount of *W—O* can be read. Thus, for Eberswalde, during the month of December, *W—O* is between two and three degrees, the soil in the forest being by that amount warmer than that in the open at 4 feet (1.22m) depth, while in the middle of July it is just five degrees lower.

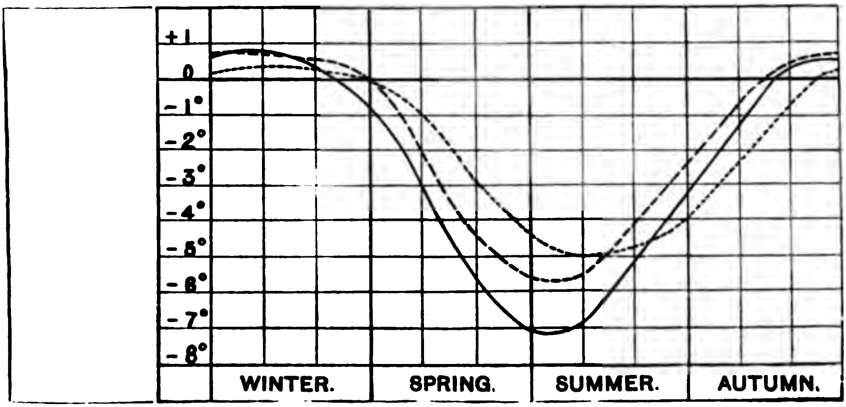


Fig. 3.—Difference of soil temperature (*W—O*), all stations—German observations.

It will also readily be seen that the values for Hollerath, Carlsberg, and Neumath are never above their zero line; that is to say, are always negative, the soil in the woods being always cooler.

This figure shows in more detail the differences between the stations which were so readily apparent in the annual means. The time of maximum is generally July, but Schoo, in a mean of ten years, gives a secondary minimum at this time, and for Carlsberg and Melkerei the maximum difference falls in August. Most of the stations give a positive sign for *W—O* in winter, some of them showing a large excess (Eberswalde+2°.41, Fritzen+2°.20); but there are several exceptions, and all those which do not cross the zero line come very near to it. The maximum monthly difference is −8°.17 for Fritzen in July. The least July value is −1°.93 (for Schoo), less than a quarter of the preceding.

The sign of *W—O* generally changes from negative to positive in December, and the reverse in March. The progress of these curves is nearly alike, and on constructing the curve for the average this appears smooth and symmetrical, as is seen in Fig 3. The dotted line here represents the progress of the differences at the depth of 4 feet. All the irregularities have here disappeared. The temperature is seen to be warmer in the woods than outside during the entire winter. It then falls rapidly during the spring, reaches its lowest point about July 1, and rises again rapidly during the autumn. The broken lines represent the progress of the difference of temperature at the depth of 6 inches and the unbroken that at the surface. The first have the smaller maximum values and also indicate a longer time during which it is warmer for woods. The maximum monthly differences are: For 4 feet, −5°.01 in July; for 6 inches, −5°.48 in June; for the surface, −7°.05 in June.

A glance at the curves shows more strikingly the retardation suggested by these values. By the course of the curves it appears that the maxima are successively later as we descend, being a full month later at 4 feet than at the surface. Probably the same thing occurs with diurnal changes; that is, they are retarded by some hours at the lower depth. It appears from these curves that, on the average, the forest soil is warmer than that of the open fields in winter, but cooler in the other seasons, and the total cooling effect is much greater than the warming one. The numerical data show that while the maximum negative value of $W-O$ at the surface is 7°.05, the maximum positive value (January) is 0°.66, or only about one-eleventh of the former. At 6 inches (152.4 mm) the numbers are 5°.48 and 0°.62, and the ratio one to nine. At 4 feet (1.22 m) they are 5°.1 and 0.36, or a ratio of one to fourteen. The forest, therefore, not only cools the soil, but also moderates the extremes of its temperature. The amplitudes of the mean monthly values are decreased by 0.66 + 7°.05 = 7°.71 at the surface, 0°.62 + 5°.48 = 6°.10 and 0°.36 + 5°.01 = 5°.37 at 6 inches and 4 feet depth, respectively, and through the soil this moderating influence must be appreciable in the air.

The stations of the German service are so happily distributed that a study can be made of the differences in the influence of deciduous and evergreen trees upon soil temperature, and also those for elevation above the sea. For the first, seven stations under deciduous trees and seven under evergreens were taken, Fritzen and Eberswalde being omitted to get a symmetrical arrangement, and Lintzel, because the trees were young. The reductions were made for the two sets of stations independently, and the results are shown in Fig. 4. The results are here plotted separately for the surface, for 6 inches, and for 4 feet. The dotted lines refer to the deciduous trees, the broken ones to the evergreens. The differences are not great, but they are quite consistent at the three depths. They may be expressed by the statement that the differences vary a little more under deciduous trees. This is what should be expected from the character of their foliage, The same explanation would suffice for the slight retardation of the fall of the curve for deciduous trees. There is one feature, however, that is unexpected. It is, that the difference between the two sorts of forests is not especially marked in winter. As a matter of fact, in the high latitudes in which the observations are taken, the sun is so low in winter that the bare trunks and branches are fairly efficient screens against his rays.

The darker color of these bodies also permits them to be more warmed up when the sun does appear. Besides, the persistent cloudiness of the winter and the covering of snow in these latitudes tend to equalize the effects of the soil of these two types of forests at this season. The annual means for the two kinds of forests differ but little.

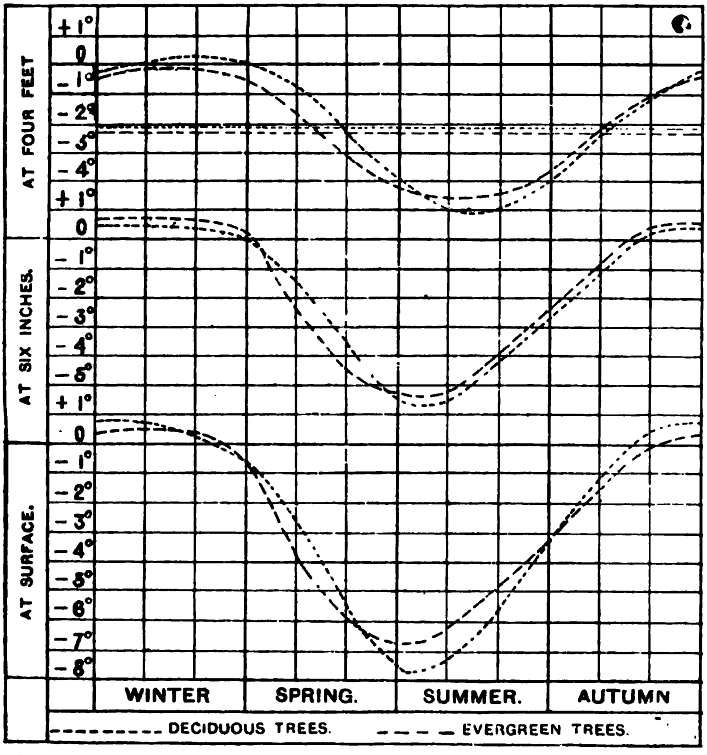


FIG. 4.—Differences of soil temperature (woods and open fields). Comparison of deciduous and evergreen trees (*W—O*).

For the surface they are −2°.57 for deciduous trees, −2°.62 for evergreen trees; at 6 inches they are −1°.89 and −1°.82; at 4 feet −2°.05 and −2°.19. They are represented in the diagram for the 4-feet depth by the two straight lines, to show the slight difference between the two types of forest cover. The difference in amplitudes is somewhat greater. The amplitudes are:

	Surface.	Six inches.	Four feet.
For deciduous trees	8°.50	6°.04	5°.12
For evergreen trees	7°.31	6°.04	4°.87

As to the effect of elevation above sea level, there are seven stations over 1,900 feet (579 meters) and seven below 500 feet (152 meters). The mean elevation of the first set was about 2,400 feet (732 meters), that of the second about 240 feet (93 meters). Lintzel was omitted, and evergreen and deciduous trees were about equally distributed in the two sets. The reductions were performed for each of these sets separately, and the results are shown in Fig. 5. The differences are a little more marked than in the case of deciduous and evergreen trees. The range is noticeably smaller at the higher levels. The forest cover there has a greater cooling effect in summer and a greater warming effect in winter. Its influence in moderating a climate is, consequently, slightly greater.

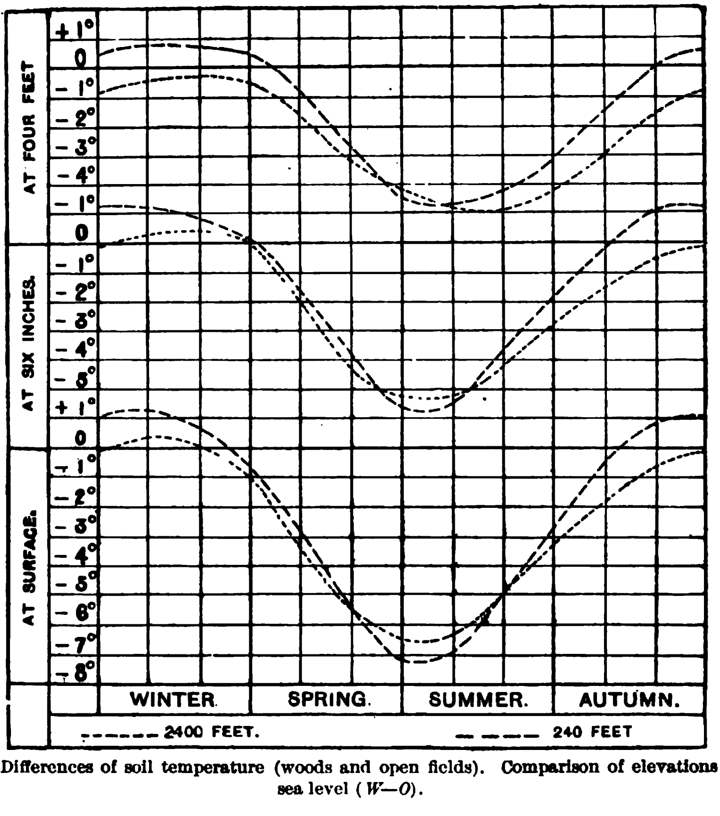
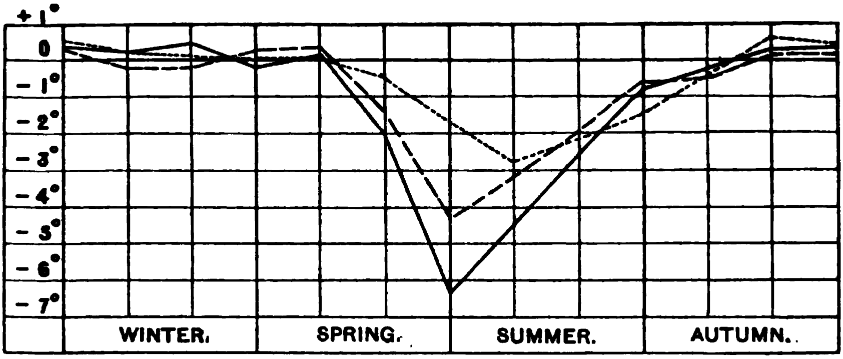


FIG. 5.—Differences of soil temperature (woods and open fields). Comparison of elevations above sea level (*W—O*).

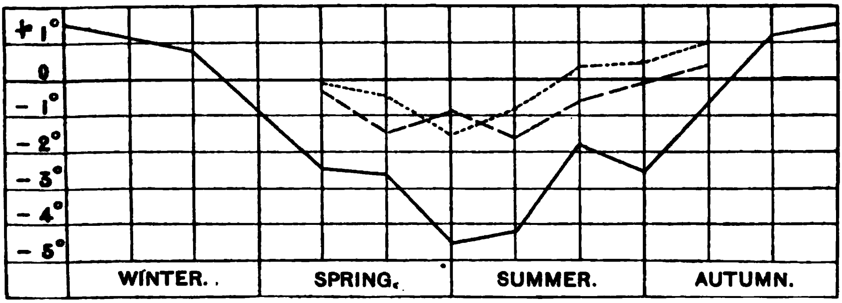
The difference in influence of young trees and old is also of interest, but the material is scanty. Lintzel is a station among young trees, but there are only seven years of observation (including 1888, the latest on hand at this writing). The curves are given in Fig. 6, and their lack of evenness betrays the brief series of observations from which they were drawn. The surface summer reduction seems very large, and that at 4 feet unusually small, but these results may be due rather to the soil at the station (Lüneburg heath) than to the trees. Dr. Wollny has made some studies of the effects on soil temperatures of vegetation at different heights and has found that on the whole they increase with the height.

That the forest litter plays an important part in the matter of soil temperature can not be doubted, but no details are given on this point in the published reports of the forest meteorological services. Numerous experimental observations have, however, been taken by Dr. Wollny, the results of which are graphically exhibited in Fig. 7. The unbroken curve is here the result of several years' observation; the broken ones represent shorter series, made to test the effects in individual soils. The comparison is always made with bare soil, and the positive sign here means a higher temperature in the covered soil. The general trend of the curves is strikingly like that in forests.



——— *At surface.* – – – – *At 6 inches below surface.* .... *At 4 feet below surface.*

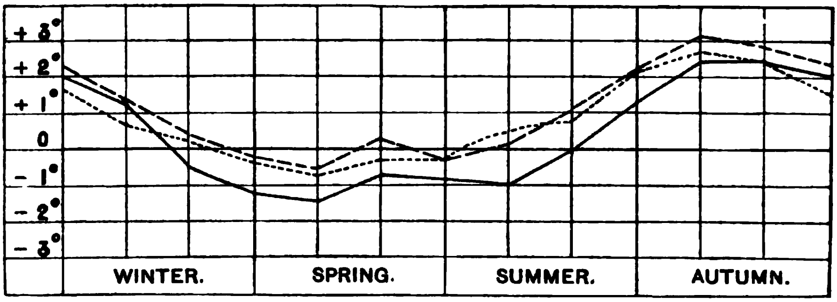
FIG. 6.—Differences of temperature for young trees, Lintzel Station, woods and open fields (*W—O.*)



——— *Average results.* – – – – *Results on loamy soil.* .... *Results on quartz soil.*

FIG. 7.—Effects of litter on soil temperature (littered surface—bare). (*W—O*).

The material at hand does not permit the study of other modifying influences—soil, latitude, prevailing cloudiness, water in the soil, etc. As a means of comparison, it may be of interest to give the progress of soil temperatures under sod as compared with that under bare soil. This is given in Fig. 8, which represents the means from an eleven-year series of observations by the MM. Becquerel. The trend of the curves is quite unlike that of the forests. The sod is relatively warmest in autumn and coldest in spring, and the mean is in favor of warmer rather than cooler temperatures. The curve is constructed on the same scale as all the other figures of this chapter. The small May indentation is very curious and is unexplained.



———— *Depth of 0.8 inch.* — — — *Depth of 4.6 inches.* .... *Depth of 9.3 inches.*

FIG. 8.—Difference of soil temperature, under sod, and bare surface (sod—bare). Becquerel's observations.

From the report of Mr. Fernow for 1889 the following tables are here reproduced, combining results of various sets of stations in different parts of Germany; the temperature is given in centigrade, the minus sign denoting lower temperature in the forest, the plus sign higher temperatures.

Differences of temperature of the soil inside and outside of a forest.

	February-April.		May-July.		August-October.		November-January.		Year.	
	Surface.	0.9 m.	Surface.	0.9 m.	Surface.	0.9 m.	Surface.	0.9 m.	Surface-	0.9 m.
Alsatian Mountains	−1.0	+0.5	−7.8	−2.8	−5.7	−3.2	+0.3	−0.7	−3.5	−1.5
Bavaria	−1.8	−0.8	−4.5	−3.9	−2.6	−3.0	0	−0.1	−2.2	−2.2
Bavaria (other stations)	−1.3	−0.6	−4.6	−4.1	−2.6	−3.0	+0.3	−0.1	−2.1	−2.0
Eastern Prussia	−1.3	0	−4.4	−3.6	−2.8	−2.2	+1.3	+0.9	−1.6	−1.0

The mitigating influence on the soil temperature appears still more clearly when the maximum and minimum temperatures for the year or the range of temperature is compared.

	Range of temperature.	
	Without the forest.	Within the forest.
	Degrees.	*Degrees.*
Bavaria	39.5	29.5
Alsatian Mountains	35	21
Eastern Prussia	41.8	26.7

TEMPERATURES OF AIR IN THE INTERIOR OF FORESTS.

We pass from the soil, which is fixed and the temperature changes of which are due to the changes of the surrounding medium, to the constantly moving air, the temperature changes of which are to some extent due to the motions of the medium itself. The results for the air from this cause are less definite, more variable, and more capricious than those derived from observations on the soil. At the surface of the soil there is only an imperfect relation between the temperatures of the soil and air. Yet it is undoubtedly true that the air temperatures near the surface are due in the first place to heat derived from the soil. It is to the motion of the air, carrying with it its temperature, that this disparity between soil and air temperatures is due.

The observations used here are those of maximum and minimum temperatures.* These afford satisfactory results, because what we are concerned with is not so much the temperatures in woods as the differences between temperatures in woods and those outside. Besides, in using the extreme temperatures, all danger is avoided of being misled by a difference in the diurnal progress of temperatures at the two stations. The extreme temperatures, also, are those which best show the influence of the forest, for this is exercised chiefly here, as in soil temperatures, in reducing the extremes. The data used are always, unless otherwise stated, the values of *W—O* (woods minus open fields reading), and it is to be remembered that a minus sign (or position below zero line) indicates colder temperatures in woods, a plus sign (or position above zero line) warmer. The observations are taken at the same height from the ground in the woods and outside.

ANNUAL RANGE.

Fig. 9 shows at a glance the mean annual values of the temperature difference of *W—O* in the case of maxima, minima, and the mean derived from them. The heavy line across the figure represents the zero line (for *W—O*=0). The annual values for *W—O* for the maxima are always negative and they are laid off to reach below the zero line. The annual values for *W—O* for the minima are always positive and they are laid off above the zero line to the same scale.

It appears at once that the action of the forest varies greatly in the different stations. It always cuts down the annual mean of the monthly maxima, but to a very variable extent. In the case of St. Johann (five years of observation) it cuts off the maxima by an average of 4°.89, but in the case of Schoo it is only 1°.44, or less than one-fourth, and in the case of the young forest of Lintzel, it cuts down the maxima by only 0°.35. The average amount of reduction for all stations is 2°.85.

---

*Dr. Müttrich has published a complete reduction of the air temperatures for the German service up to 1890. It may be found in Danckelmann's *Zeitschrift für Forst und Jagdwesen*, XXII, 1890, 396 and 397.

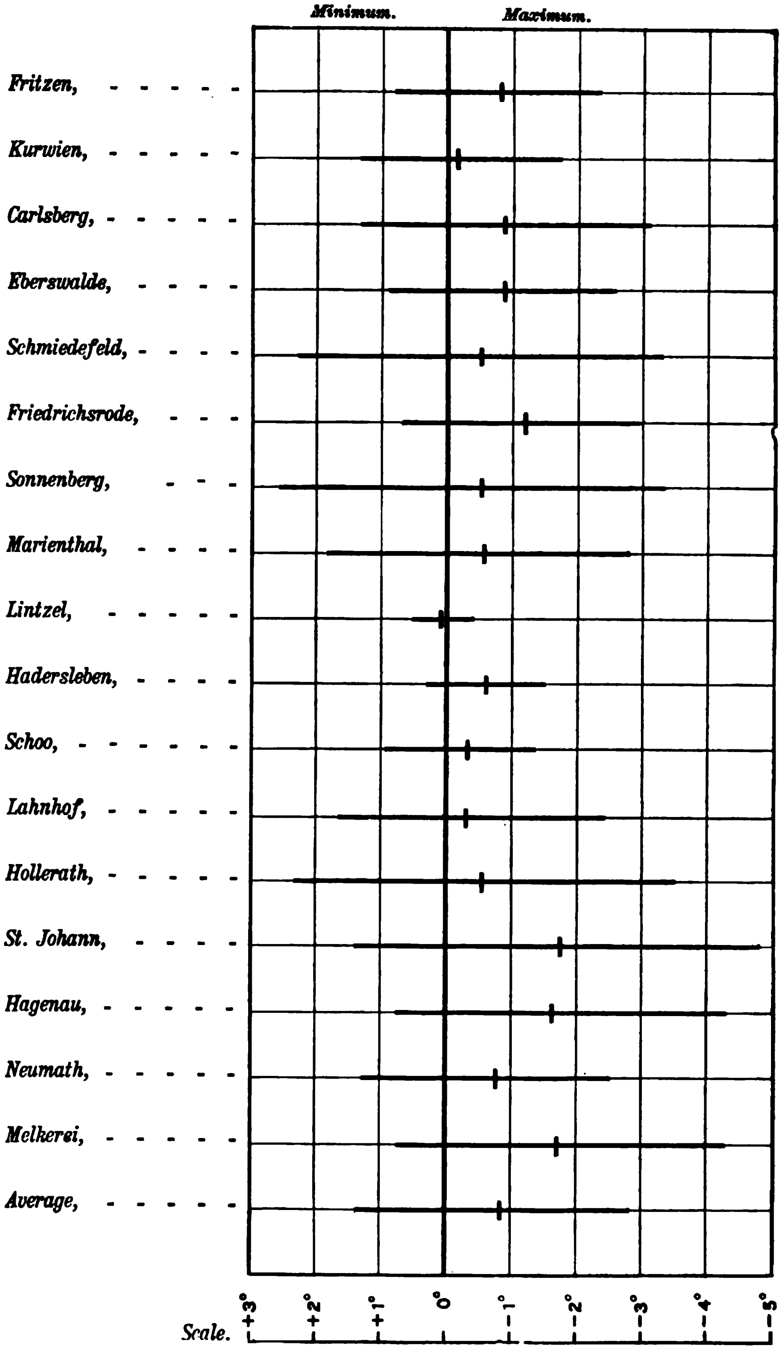


FIG. 9.—Forest air temperature differences ($W-O$). German stations. Mean annual (cross-bar), maxima (below zero line), minima (above zero line), and range (length of lines).

Very much the same is true of the minima temperatures. They are always cut off in the annual mean, but by a varying amount. The largest reduction of the minima is for Sonnenberg (2°.56); the smallest is for Melkerei (0°.74), except for the young forest of Lintzel station, where it is only 0°.43. The average amount is 1°.33.

The length of the lines opposite the names of the stations in Fig. 9 indicates the reduction of the range in temperature in the woods as compared with the outside. This is a reduction of range, because the forest lowers the highest temperatures of the day and raises the lowest. This reduction varies like the preceding, of which it is the sum for each station. For St. Johann it is 6°.25, for Sonnenberg 5°.92, while it is only 1°.86 for Hadersleben and 0°.78 for Lintzel. This is a measure of the degree by which the air temperature is moderated in the woods in the average. The absolute moderation is often greater, as the woods become more efficient in reducing greater extremes, especially in lowering the highest temperatures. This is seen by considering the absolute range for the year—that is, the number of degrees between the highest temperature for the year and the lowest. The mean of the absolute annual ranges at all the German stations is for the open fields 92°.90, for the woods 81°.86, which gives a reduction of 11°.04. The mean range for all stations is 4°.18, or but a little more than a third of this. The value of *W—O* for the mean annual temperatures is one-half of the sum of the value of *W—O* for the maxima and minima. The reduction of the minima is always less (except for Lintzel, young woods) than the reduction of the maxima, and the combined effect is necessarily a cooling one. On Fig. 9 the position of the mean temperature compared with the zero line is the point in the middle of the line representing the range of *W—O* for each station. This is marked by a short cross line. It will be observed that in every case, except the one mentioned, this mark falls below the zero line, or on the cooling side.

The amount of reduction of the mean temperature varies with the reduction of the extremes, and is very different for different stations. For St. Johann it is 1°.76, for Melkerei it is 1°.72, but for Kurwien it is only 0°.17, while for Lintzel the mean temperature is 0°.04 higher in the woods than out. The average reduction of mean annual temperature for all the German stations is 0°.76.

It appears, therefore, that *the forest moderates* (by reducing the extremes) *and cools* (by reducing the maxima more than the minima) *the temperature of the air within it. The moderating influence is decidedly greater than the cooling effect.*

MONTHLY RANGE.

On taking up the consideration of the mean monthly values of *W—O* a very curious series of results appears. Fig. 10 illustrates the influence of the forest on the temperature of its interior air at Friedrichsrode, but is a type of all the curves, differing chiefly in the magnitude of the changes it indicates, The line of zero differences is used as the base line of the diagram. On it are laid off, at equal distances, seasonal lines, on which the values of *W—O* for the monthly minima are measured off, above the zero line if plus, below if minus. The points thus obtained are connected by the dotted line above and this, therefore, is the curve representing the reduction (*W—O*) of the minima. In exactly the same way are constructed the curves for the mean monthly values for *W—O* for maxima, represented by the broken line, which is, therefore, the curve for the reduction of the maxima for the year. Between these two curves is drawn a curve with unbroken line, which represents the reduction (*W—O*) for the mean temperatures. This figure shows at a glance all the details concerning the influence of the forest on its own interior air temperatures. The distance vertically between the exterior curves is the reduction of the range. The space between the middle curve and the zero line represents the change in mean temperature due to the influence of woods, cooling if the curve lies below, warming if it lies above, the zero line. Where it lies below, the space has been shaded to show plainly the amount of cooling. In this diagram, therefore, is shown the progress of all these elements during the year. Analyzing the progress for Friedrichsrode (Fig. 10) we see that the minima in the woods do not differ much from those outside between November and April. Then the forest begins to affect them and the curve for *W—O* for minima rapidly rises above the zero line. It reaches the greatest distance in August, approaching the line again from September to November, when the minima are once more closely alike in the forest and outside. The forest has the greatest effect on the minima in summer, somewhat less in May and September, still less in April and October. For the values of *W—O* for maxima the progress is much the same, only in the reverse direction and two or three times as great in magnitude. The greatest effect here falls in July instead of August. It gives form to the *W—O* values for mean temperature, for which the greatest value falls in July. It appears also that the temperature in the woods is almost always lower than in the open fields. In March it is about the same; in winter it is a little cooler; in summer it is decidely cooler, especially in July.

These figures for *W—O* are variously modified in the various stations. Fig. 11 (Hagenau) shows a case where the reduction of the minima, especially in summer, is relatively small, and the mean temperature of the woods is less for the entire year. Fig. 12 (Sonnenberg) represents a case where the reduction of minima is almost as large as that of the maxima and there is little reduction in mean temperatures. In fact, the woods here are warmer in winter. In Fig. 13 (Eberswalde) the reduction of mean temperature is small and continues during the year, like the preceding, but for a different reason the reduction of maxima and minima here run symmetrically, but shows no great difference in quantity.

Forest air temperature differences, woods and open fields (*W—O*).

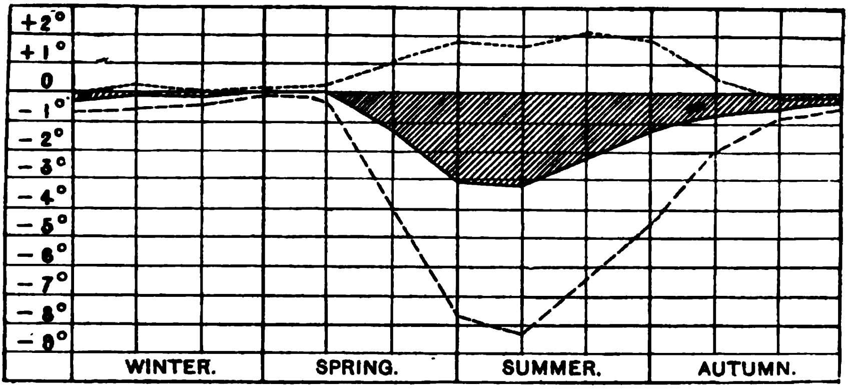


FIG. 10.—Friedrichsrode.

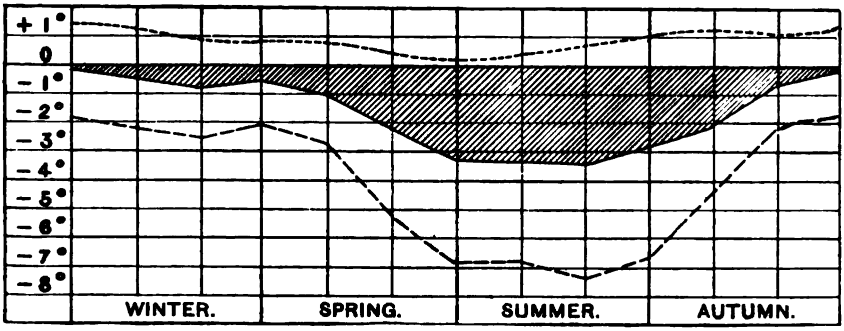


FIG. 11.—Hagenau.

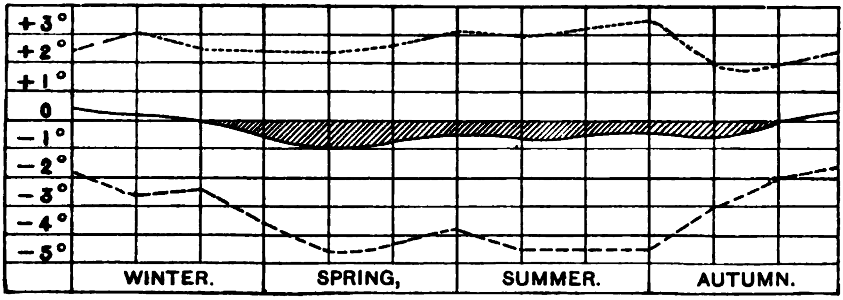


FIG. 12.—Sonnenberg.

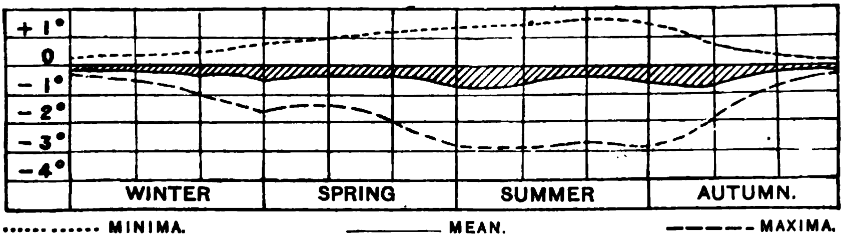


FIG. 13.—Eberswalde.

Fig. 14 (Schoo) shows a small reduction of mean temperature limited to late summer and early autumn. Fig. 15 (Marienthal) shows a curious aberrant case. The woods in March and April are warmer than the fields. But Fig. 16 (Hadersleben) is perhaps the most curious of all. Here the maxima of temperature are higher in the woods from November to April than they are in the fields, and during the same time the minima are lower. The temperature range through these months is, therefore, greater in woods than outside. But the increase in range is small and the mean temperatures are about the same in woods and outside.

These figures, all of which, except the first, have been selected because they were peculiar, are instructive in showing how extremely forest action varies while preserving consistently its characteristic features. The variations are due to the causes mentioned under soil temperatures, with the addition, in this case, of disturbances due to prevailing winds. The average effects in which these disturbing actions are eliminated more or less completely are illustrated in Fig. 17. As this represents the result from sixteen stations, through about two hundred years of observation, it may be considered fairly typical for middle latitudes. From this diagram it appears that—

(1) As to minima, the forest reduces them with fair uniformity during the entire year. For about half of the year they are reduced about a degree Fahrenheit. In April this reduction begins to increase; it grows gradually until it reaches a maximum of about 2 degrees in August. From this it lessens until November, when its average value is 1 degree.

(2) As to the maxima, these are reduced about 1 degree in December. This reduction grows slowly until it reaches about 2 degrees in April. From this it grows very rapidly until it reaches about 5 degrees. It remains at about this value during the summer and decreases rapidly during the autumn to its December value.

(3) The reduction of range is about 2 degrees in the winter, 6 or 7 degrees in the summer, and an intermediate amount in spring and autumn.

(4) As to mean temperature, it is 1 or 2 degrees cooler in the woods in summer, about the same in woods and open fields during the winter, and intermediate in spring and autumn.

(5) The moderating and cooling effects of woods already mentioned as a phenomenon of mean annual temperature extend, it appears, through the entire year, but they are especially marked in summer. The cooling effect tends to disappear in winter. The moderating effect is the most important one, and it is the most characteristic.

It has often been claimed that forests warm the air of their interior in winter, but the German observations do not show this. On the other hand, there is an occasional warming effect in early spring, while in winter the woods are usually slightly cooler than the open fields.

Forest air temperature differences, woods and open fields (*W—O*).

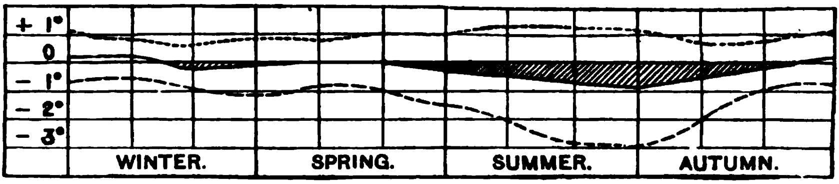


FIG. 14.—Schoo.

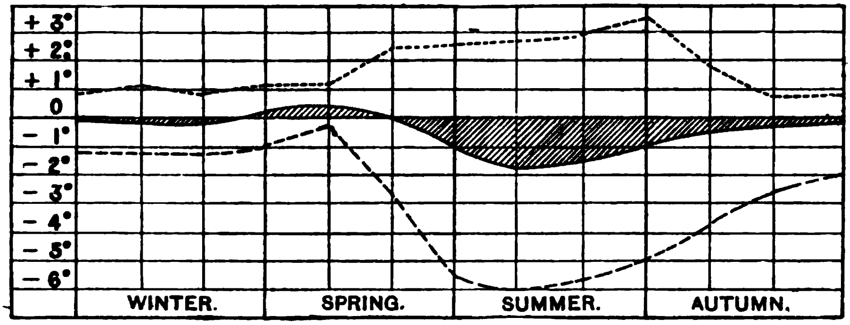


FIG. 15.—Marienthal.

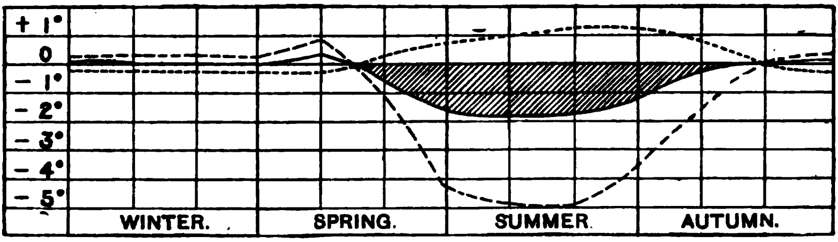


FIG. 16.—Hadersleben.

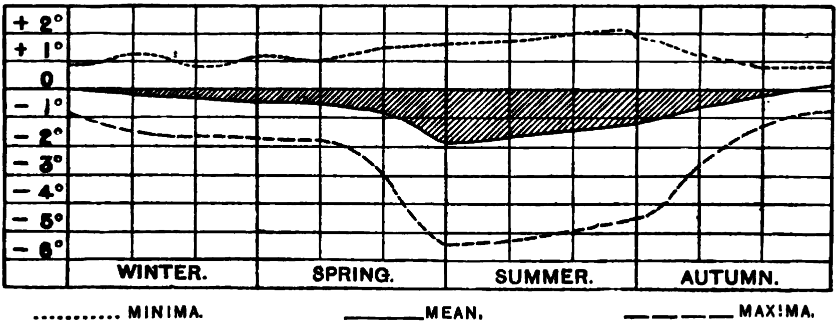


FIG. 17.—Average.

M. Becquerel found in his observations that the woods were decidedly cooler during persistent cold weather. For instance, at La Salvionnière during unusually cold weather, from the 24th to the 30th of December, 1867, the temperature in the woods was 21.4° while that outside was 22.0°. From the 1st to the 12th of January, 1868, the temperature in the woods was 14.5° while that outside was 15.8°. For the stations near Chatillon-sur-Loing, at which Becquerel took his observations, the forest temperature for the latter dates averages 13.3° while the temperature in open field was 14.4°. He noted this in other cases and thought that the lower the temperature in extreme cold weather the lower relatively it was in the woods. This is, however, not always the case. In Dr. Ebermayer's published series of observations there is only one case out of seven where the extreme temperature was lowest in the woods and this was only by a little over one degree. On the other hand, at Seeshaupt, on January 25, 1868, the temperature in the fields was −20.4° while in the woods it was only +2.1°, or a difference of 22.5° in favor of the woods. These are extreme and not mean temperatures, but the published data do not permit the study of the daily mean temperatures. Rivoli made a special study of this subject and came to the conclusion that the relative winter cold of forests was quite dependent on the direction of the wind. In Posen, 146 single observations from November to March gave a warmer temperature in the woods except for south and southwest winds, when the forest temperature was lower by a fraction of a degree.

The published observations are not complete enough to give a good idea of the diurnal progress of temperatures under trees, but several students of the subject (Becquerel, Rentzsch, Bergen) find that it is of the same character as the annual progress. They generally represent the daily minimum temperatures of woods as being higher than those outside.

DECIDUOUS AND EVERGREEN FORESTS.

The German observations permit a study of the effects of different kinds of trees. The stations were classified for deciduous and evergreen forests as in the section on soil temperatures, and the means of the values of *W*− *O* were calculated separately for each. The results are graphically represented in Figs. 18 and 19. The difference between them is much more striking than was the case with soil temperatures. The evergreen trees show a symmetrical increase in the reductions of maxima and minima until late summer, when they rapidly and symmetrically decrease. The greatest reduction of the maxima is 4.21° (August), the least 1.20° (December). The average reduction of maxima is 2.92°. The greatest reduction of minima is 2.20° for September, the least 1.29° in November, but it runs capriciously from 1.29° to 1.68° from November to May.

Forest air temperature differences of woods and open fields (*W—O*).

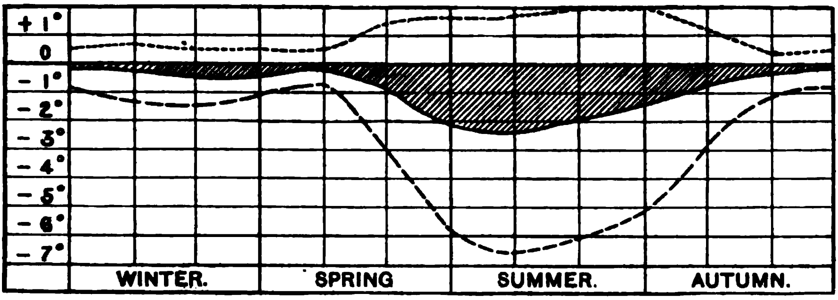


FIG. 18.—Deciduous trees.

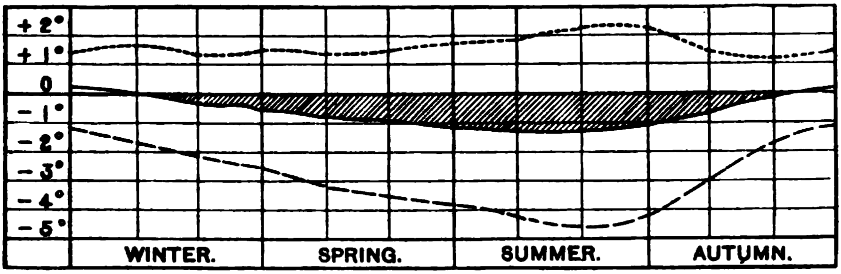


FIG. 19.—Evergreen trees.

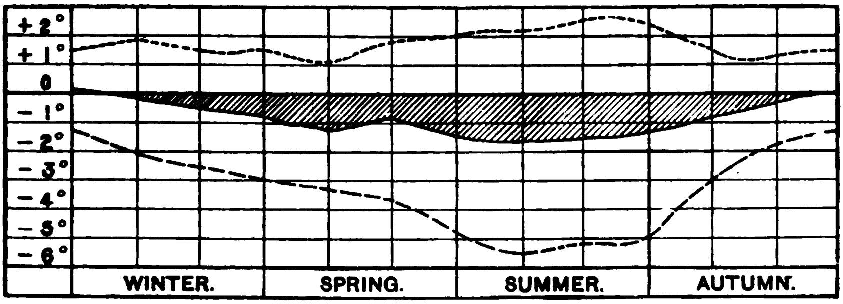


FIG. 20.—Elevated stations.

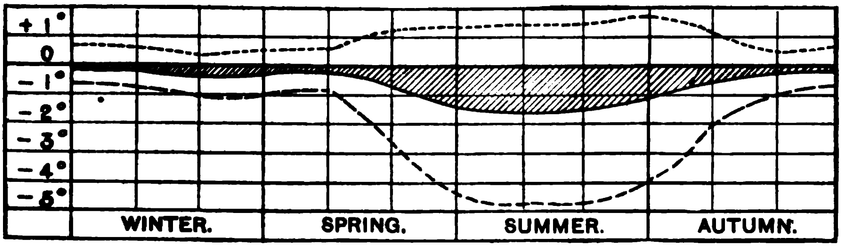


FIG. 21.—Near sea level.

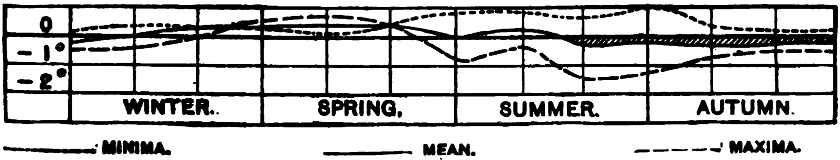


FIG. 22.—Young forest (Lintzel).

The mean annual reduction of the minima is 1.66°. The cooling of the woods takes place throughout the year, greatest (about one degree) in summer, least (almost nothing) in December and January.

On the other hand, under the deciduous trees the time of appearance and disappearance of the foliage is very plainly observable in the temperatures. The year starts out with them as with the evergreen trees, but in early spring the influence of the forest shrinks and tends to disappear. With the appearance of the leaves, in May and June, it grows again and very rapidly, so that the greatest effect is brought on in two months; through June and July it remains constant, but in August it begins to shrink rapidly, and by November it has again approached the degree of influence exhibited under the evergreen form. The greatest effect on the maxima is observed in July, when the reduction amounts to 6.50°, the least in April, when it is only 0.65°. The average is 2.92°, exactly that for evergreens. The reduction of the minima is greatest in September (2.03°), least in February (0.50°) and November (0.53°). The average is 1.14°—half a degree less than for the evergreens. The mean reduction of minima under deciduous trees is 0.89°, under evergreens 0.63°. The mean reduction through the year is curiously alike for evergreens and deciduous trees. The main difference is found in the values of *W—O* in spring and summer. In early spring the deciduous trees have a scarcely appreciable effect on the temperatures; in summer their effect is to lower the temperature two degrees or more, about twice that of evergreens.

As to the effect of elevation above the sea, the stations were classified as in the section on soil temperatures and the results are represented in Figs. 20 and 21. These figures do not differ essentially. The effects on the elements are somewhat greater at the higher station and the cooling caused by the forest extends through the year more evenly. The difference is, however, very slight when expressed in terms of the reduction of the mean temperature. For elevated forests the reduction is 0.84°, for those near sea level, 0.66°.

It will be of interest to see what is the effect of a young forest on the temperature in it. Fig. 22 gives the results for Lintzel. The series of observations was only seven years long and this is not long enough, it appears, to give good even curves. It is curious to see that this curve hardly suggests those found for mature forests. The minima are always reduced, but the maxima are exaggerated in spring. Besides the reduction of mean temperature has almost disappeared and is confined to late summer and autumn. As a matter of fact this is hardly a case of temperatures under trees. It is rather a case of temperatures in the foliage and corresponds to temperatures in tree tops in mature forests.

In the following table, taken from Mr. Fernow's report for 1889, the maximum, minimum, and mean temperatures at various forest stations are compared, the plus sign denoting higher the minus sign lower temperatures than those observed in the field stations, in centigrade readings:

	February-April.			May-July.			August-October.			November-January.			Year.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
Central Italy *	....	....	....	−4.1	+1.6	−1.2	−3.6	+1.1	1.3	....	....	....	....	....	
Eastern France †	−0.8	+0.8	0	−3.2	+1.2	−1.0	−2.6	+1.8	−0.6	−0.9	+0.6	−0.1	−1.9	+1.0	−0.4
Alsatian Mountains ‡	−1.1	+1.9	+0.4	−2.5	+1.9	−0.3	−1.9	+2.4	−0.2	+0.9	+1.7	+1.3	−1.2	+2.0	+0.4
Bavaria §	−0.5	+0.2	−0.3	−2.2	+1.1	−0.9	−3.2	+1.6	−0.8	0	+1.2	+0.6	−1.5	+1.0	−0.3
Eastern Prussia ‖	−0.7	+0.1	−0.3	−1.4	+0.5	−0.4	−1.6	+0.2	−0.7	−0.3	−0.2	−0.2	−1.0	+0.2	−0.4

*Station Vallambrosa, Tuscany.
†Station Bellefontaine, near Nancy.
‡Station Melkerei, in the Vosges Mountains.
§Stations Seeshaupt and Rohrbrunn.
‖Stations Fritzen and Kurwien.

TEMPERATURES IN THE TREE CROWN AND ABOVE TREES.

The observations used in the preceding section were all taken at the usual height; that is, about 5 feet (1.5 m.). The Swiss forest observations are taken at a height of 3 meters or about 10 feet. I have not been able to consult these observations except for a single year, that of 1876. In Lorey's Handbook of Forestry there are given seasonal means for twelve years from three stations, Interlaken, Pruntrut, and Berne. These give, in Fahrenheit degrees, for winter, *W*—*O* 0°.92 for spring, 1°.33; for summer, 2°.72, and for autumn, 1°.57. These are of the same general character as those taken at an elevation of 5 feet. The large value of *W*—*O* for spring makes them resemble more the values given in the preceding section for stations at high elevations above sea level. This is to be expected, as the Swiss stations are at the elevation of 2,034 (620 m.), 1,476 (450 m.), and 1,946 feet (593 m.), respectively. Observations are also taken by the Bavarian and German services in the tree crown. A place is selected in the top of the tree, but under the thatch of foliage. This is as nearly as practicable vertical over the instruments placed at the surface, and observations on temperature are here made at the same time as at the surface. The discussion of these observations lies under two serious disadvantages. In the first place, there is generally no station at the same elevation outside the woods, and, in the second, the tree-top stations are necessarily at different heights, thus making impossible a direct comparison between stations.

The first difficulty may be overcome by making a fictitious outside station and giving the ground station temperatures a correction for known mean variations of temperature with altitude. Unfortunately this reduction of the surface observations to a given altitude can not be made without considerable uncertainty. The change of temperature with altitude alters with almost every source of meteorological change, with season and time of day, with the topography, the character of the soil and its covering, and with the weather, and the amount of change is especially variable within the first 50 feet from the surface, within which range must be made the correction we propose to apply. However, the correction is a small one, and over the territory occupied by the German stations it is known with more accuracy than elsewhere generally.

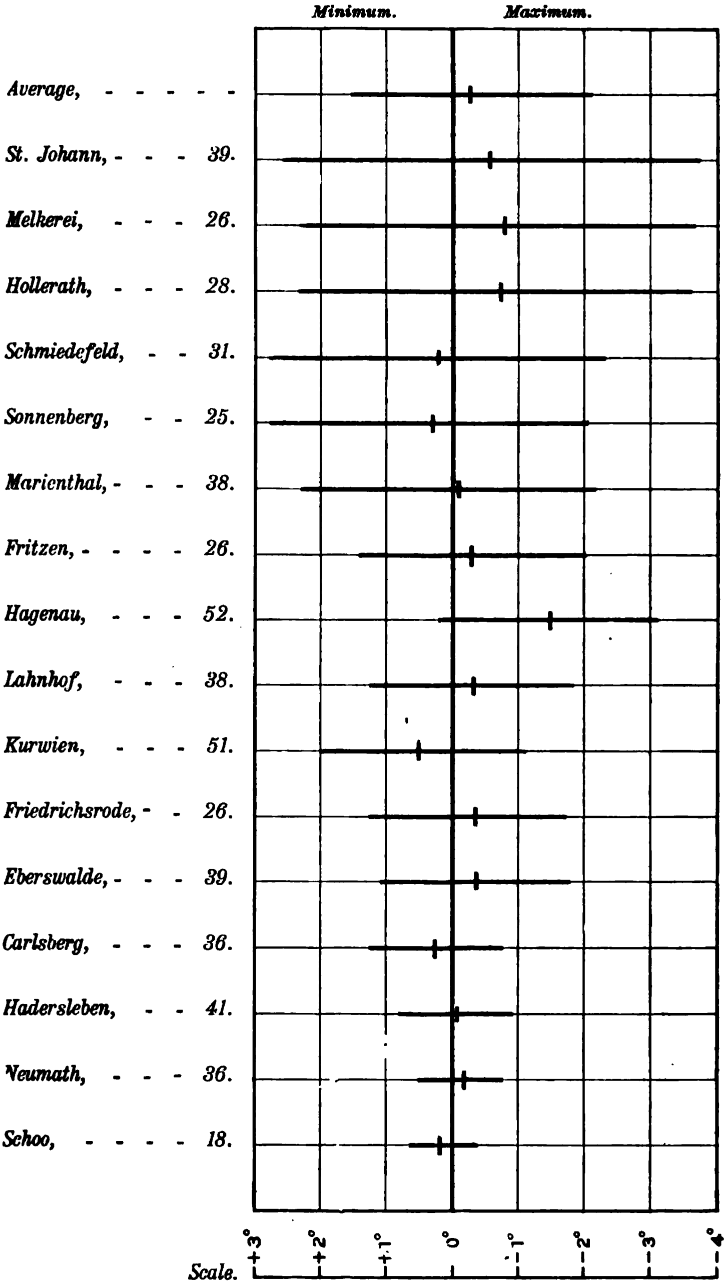


FIG. 23.—Forest temperature differences for the year at height of the tree top (*W—O*).

The correction which is used is that given by Mr. Ferrel in his "Recent Advances in Meteorology," and is taken from the column for "the Alps and Germany" in the table on page 180. In no place does this correction, as applied to the German tree-top observations, surpass 0°.11 F. (0.06°C.), and it is always negative. After making this correction the observations will be treated as if the fictitious elevated stations were real and the values of *W'*—*O'* (here primed to distinguish from those at the level of 5 feet) will be discussed as were those of *W*—*O* in the preceding section.

Fig. 23 represents the mean annual values of *W'*—*O'* for maxima and for minima; the maxima always negative and below the zero line, the minima always positive and above. The names of stations are placed opposite the lines which belong to them, and for each station is given the elevation in feet above the surface of the ground. As in the preceding section, the length of the line indicates the reduction of range of temperature in the tree top, as compared with that outside at the same height, and the point in the middle of the line (marked by a short cross bar) indicates the reduction of mean temperatures.

This diagram presents the same features as the corresponding one for lower levels, but there is, if anything, more variation for the individual stations. Also, the mean temperature is here sometimes higher in the tree tops than over open fields. This is the case in five out of sixteen stations.

It is noteworthy that the reduction of the annual temperature in tree tops does not appreciably depend on the height of the station above the ground. The lowest (Schoo) shows the smallest reduction of temperatures. It should have the largest because nearest the ground. On the other hand, the highest station (Hagenau) stands about midway. The next highest (Kurwien) stands somewhat lower in the series, while one of the two next highest (St. Johann) leads the series. Nor does any feature (reduction of maxima, minima, or mean temperature) show any distinct distribution with reference to the height of the station.

Taking up the individual tree-top temperature diagrams, we find them strongly resembling those for the observations at the 5-foot level, but with greater variation between the individual diagrams. That for Friedrichsrode (Fig. 24) is a fairly smooth and representative one, and it greatly resembles those of the preceding section. The minima are raised, the maxima lowered, the action is a cooling one, and it is most marked in summer. These features are all visible in the temperature diagrams at the 5-foot level. The cooling effect is, however, sometimes distributed through the year with some approach to evenness.

The reduction of the minima is often relatively great (Fig. 26, St. Johann). It is not rare that this is greater than the reduction of the maxima, leaving not a cooling, but a warming, action on the part of the woods.

Tree-top temperature differences woods and open fields (*W—O*).

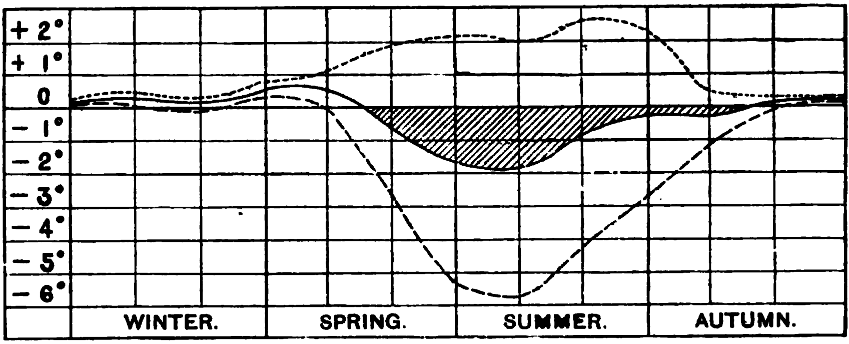


FIG. 24.—Friedrichsrode.

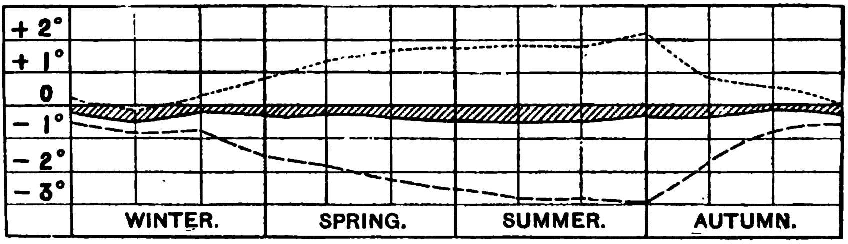


FIG. 25.—Eberswalde.

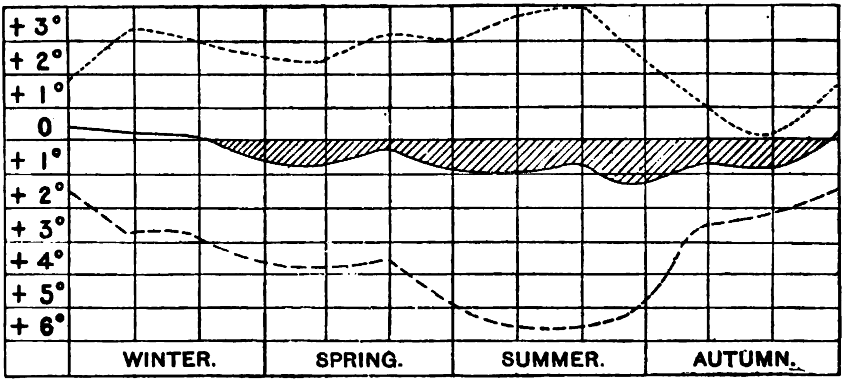


FIG. 26.—St. Johann.

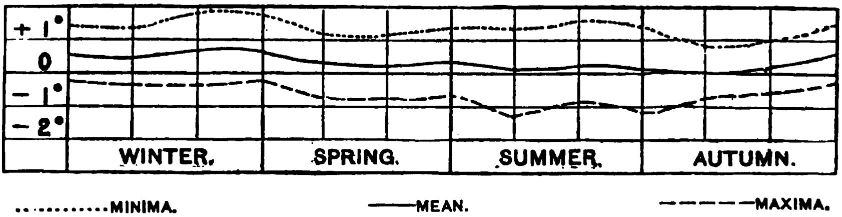


FIG. 27.—Carlsberg.

Tree-top differences (*W—O*).

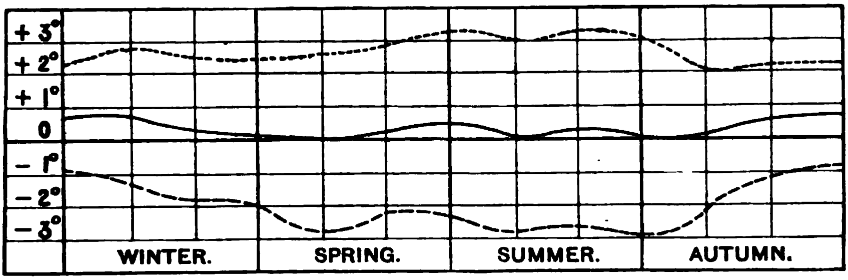


FIG. 28.—Sonnenberg.

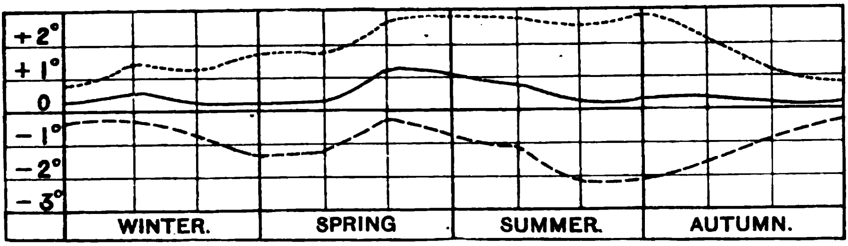


FIG. 29.—Kurwien.

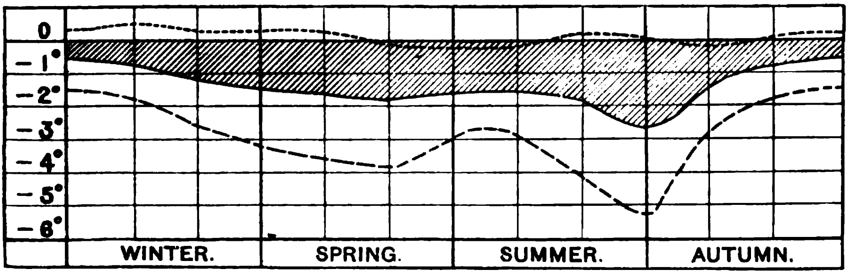


FIG. 30.—Hagenau.

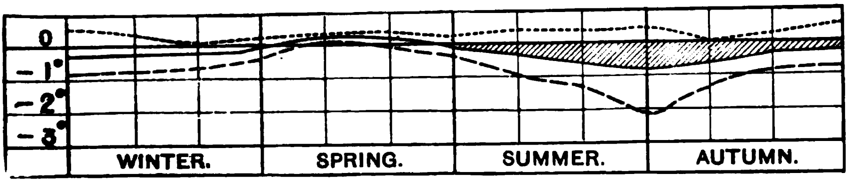


FIG. 31.—Schoo.

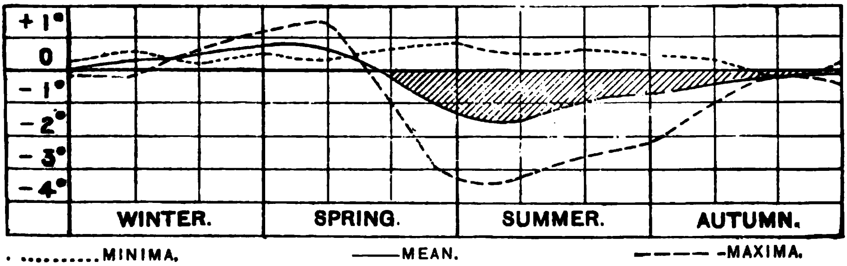


FIG. 32.—Neumath.

Fig. 30 is that for the station with the greatest elevation above the surface (Hagenau), and Fig. 31 that for the least (Schoo). They show great differences, but there is no connection between the diagrams through those for the intermediate stations. They are alike, and of especial interest, in that in both the reduction of the minima is only a small fraction of a degree. Fig. 32 (Neumath) gives the only case where the maxima was warmed decidedly more than the minima. This increases the range and makes the temperature more excessive in the late winter and early spring months.

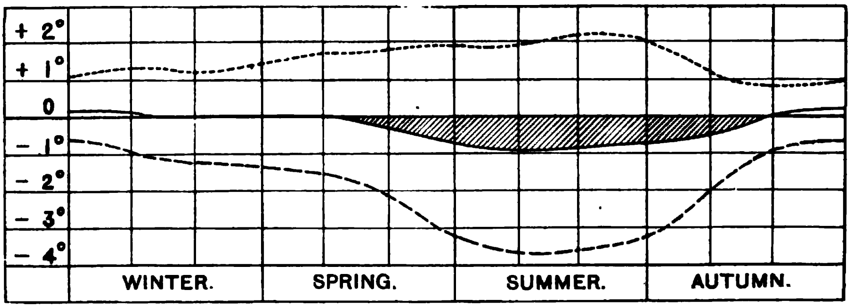


FIG. 33.—Average differences of tree-top temperature, sixteen German stations (*W—O*).

The average differences of tree-top temperatures (*W′-O′*) are graphically given in Fig. 33. It is at once seen to be very similar to the corresponding figure (17) for the elevation of 5 feet. There is the same elevation of minima, the same lowering of maxima, the same cooling effect, and the same exaggeration of all features in summer. The reduction of minima is, however, more nearly equal to that of the maxima, and there is, consequently, less cooling. It seems, therefore, that the tree-top station is intermediate in temperatures between the base station and that in open fields.

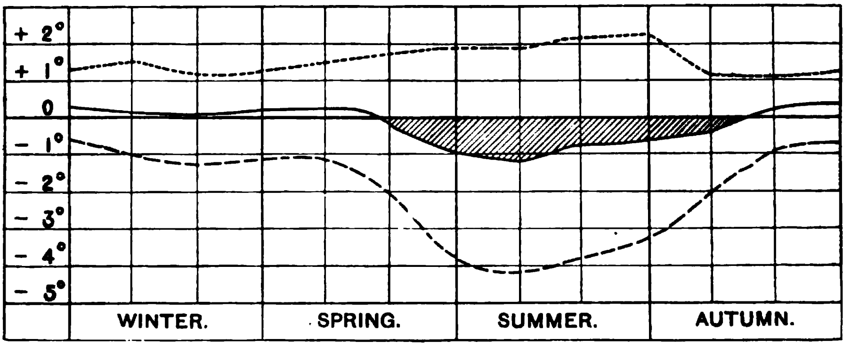


FIG. 34.—Tree-top temperature differences for four stations with average height of 24 feet.

It will be interesting to see if there is any difference through the year on account of elevation of the tree tops above the ground. To ascertain this the two lowest stations were taken (two in evergreens and two in deciduous trees) and their values of *W′-O′* were combined. The result is Fig. 34. The average height was 24 feet. The four highest (also equally divided between deciduous trees and evergreens) were similarly treated, with the result shown in Fig. 35. There appears no unmistakable difference between them due to anything but individual irregularities.

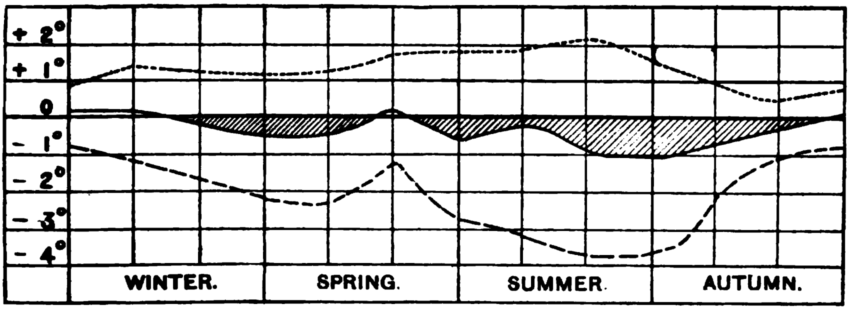


FIG. 35.—Tree-top temperature differences for four stations with average height of 46 feet.

The stations for deciduous trees and for evergreens were then averaged separately, as for the preceding stations. Fig. 36 is the diagram

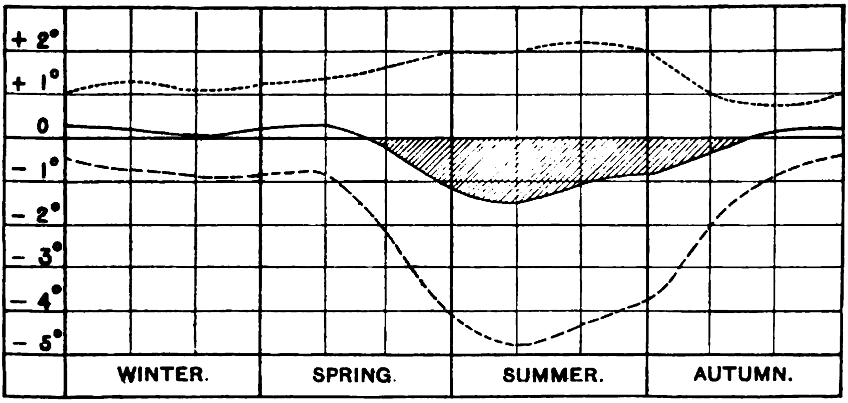


FIG. 36.—Tree-top temperature differences, German stations (*W*— *O*)—deciduous trees.

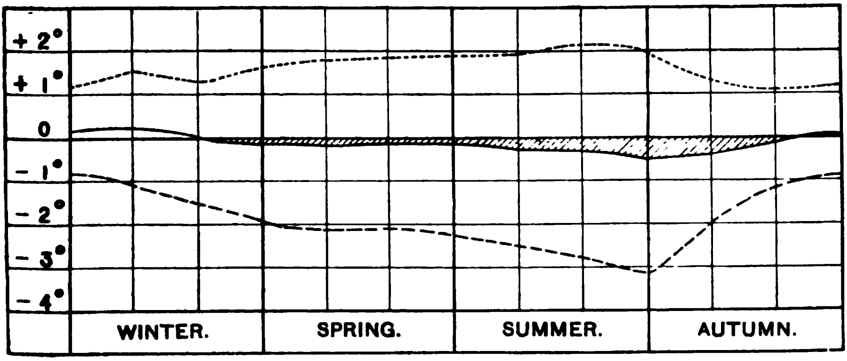
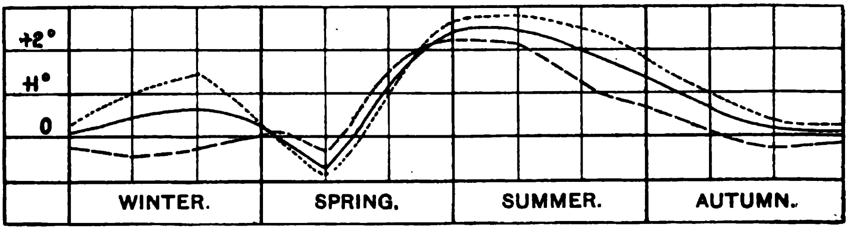


FIG. 37.—Tree-top temperature differences, German stations (*W*— *O*)—evergreen trees.

for deciduous trees; Fig. 37 for the evergreens. The reductions for evergreen trees are less in quantity than for the deciduous, and are distributed more evenly through the year.

TEMPERATURE GRADIENTS.

So far the discussion has been as to change of temperature horizontally, or the horizontal temperature gradient. The tree-top observations permit also the study of the vertical distribution of temperatures, and this is a matter of considerable interest, because from it can be drawn some conclusions as to the stability of forest air; that is, as to its tendency to originate meteorological disturbances or to take part in those which approach it. This can be studied within the forest, because there are two stations—one above the other; but it can not, unfortunately, be studied outside the forest, as the station there, in the usual meteorological services, is single. In order to get around the difficulty that the stations are not at the same height, the gradients are expanded to the uniform height of 100 feet; that is, the vertical temperature gradients in the figure are those which would occur in forests if the temperature continued to change at the same rate through 100 feet (30.48 m.). The height of this assumed station is its height above the ground, decreased by 5 feet (1.5 m.) (the height of the lower station). As the irregularities in the vertical differences are exaggerated in increasing them for 100 feet, only the data from the eight highest stations were used. These give a distance between lower and upper instrument of from 31 to 48 feet, averaging 38 feet (11.6 m.). Three of these stations were for evergreen trees (average distance 43 feet) (13 m.) and five deciduous (averaging 35.5 feet) (10.8 m.). These were arranged separately.



— — — — *Deciduous trees.* .... *Evergreen trees.* ——— *Average of all.*

FIG. 38.—Vertical temperature, gradient in woods, degrees Fahrenheit for 100 feet.

The results appear in Fig. 38. The unbroken line represents the gradients for the average of all eight stations, the broken line for the evergreens, and the dotted line for the deciduous trees. The vertical gradients are surprisingly large, when compared with the average. In no case would the latter be more than 0°.25, and it would always be negative. Here the gradients vary from 0°.61 F. per 100 feet in April (for deciduous trees 0°.77, for evergreens 0°.35) to + 2°.50 in July (deciduous + 2°.62, evergreens + 2°.31). In summer the average gradient under trees is about + 2°; that is, it grows warmer as we ascend at the rate of two degrees per 100 feet (31 m.). Outside in the general average it grows colder by about a quarter of a degree. In early spring the gradients are somewhat alike in and out of woods. In other parts of the year it generally grows warmer as one ascends.

A higher temperature of the air above than below is called a reversal of the vertical gradient, and it appears that in the woods this reversal occurs especially in summer. It also occurs in the open air regularly at night and often becomes very marked on a clear summer night, especially toward morning. The gradient is at such times generally three or four degrees and may, under exceptionally favorable circumstances, be several degrees more. The same thing is true throughout the day in the winter months, but the gradient is then not generally large. The action of the forest, therefore, tends to produce a vertical distribution of temperature like that over snow, or over level fields on clear summer nights. It should be noted that this arrangement is in favor of stability of the air. The warmer air is the lighter and is on top. Still this tree-top air is, in the warm season, usually cooler, and consequently heavier than the air at the same level outside, as is shown by Fig. 38. This is true of the entire column of forest air—that is, air in the forest—and this heavier air will tend to flow out.

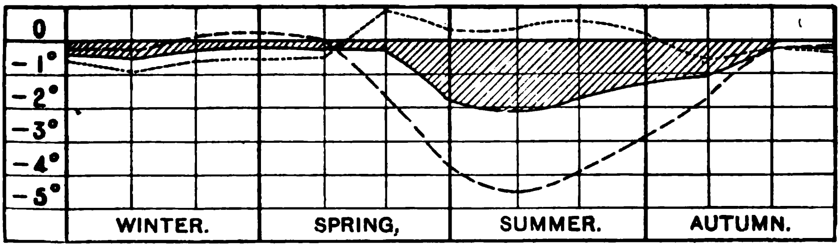


FIG. 39.—Forest temperature, differences at Halatte, under deciduous trees.

TEMPERATURE ABOVE FORESTS.

Systematic observations above forests have been seldom taken. Among them are those taken by M. Fautrat a few miles north of Paris, in the forests of Halatte and Ermenonville. In the first the observations were under and over deciduous trees, oaks, and hornbeams, in the second over pines. The soil at the latter place was a coarse quartz sand, and the open field station was over a sandy plain. The surface observations were taken at a height of 1.4 meters (4 feet 7 inches), while those above trees were 14 meters (46 feet). The instruments appear to have been close to the top of the pines, but many feet above the deciduous trees. The published observations are somewhat fragmentary, from two to four years being available. The temperature diagrams near the ground are given in Figs. 39 and 40. The first is for the deciduous forest and is of the familiar type. Fig. 40 exhibits some striking peculiarities, chiefly in the exaggeration of the minima and the constantly cooling mean temperature. These features may be in part due to the soil. Otherwise the diagram resembles the corresponding one of the preceding section. Fig. 41 gives the two forest temperature diagrams above trees from M. Fautrat's observations. The line for mean temperature is omitted because of the narrowness of the space. It would, in each case, hug the zero line. It is interesting to note how the temperature diagram, in Fig. 41, has here contracted. That for evergreen trees, with the instruments close to the tops, is very narrow, while that for deciduous trees, instrument about 20 feet above the tops, has contracted so as to vanish at times. It is evident that if the instruments had been put a few feet higher up it would have entirely disappeared. Fig. 42 represents the vertical gradients from M.

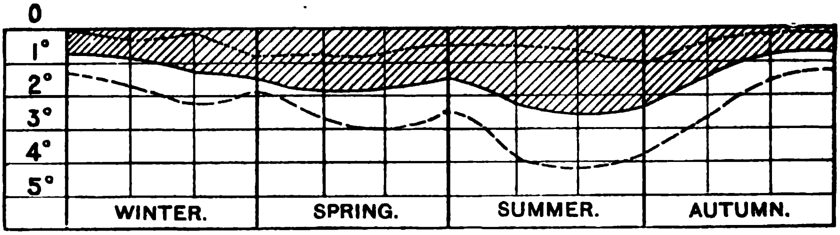


FIG. 40.—Forest temperature, differences at Ermenonville, under pines. Soil: coarse, bare sand.

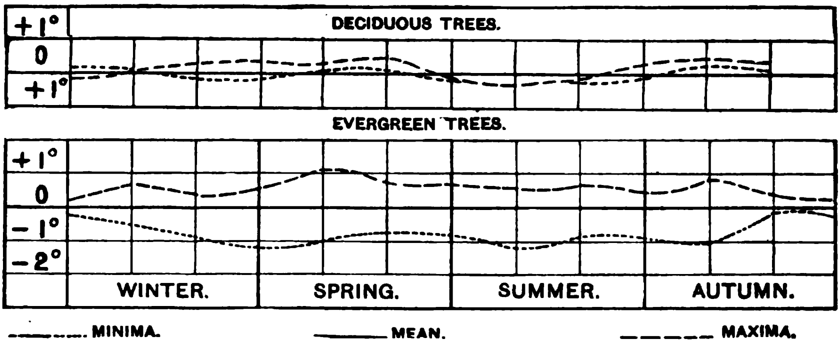


FIG. 41.—Forest temperature, differences above trees—from Fautrat's observations.

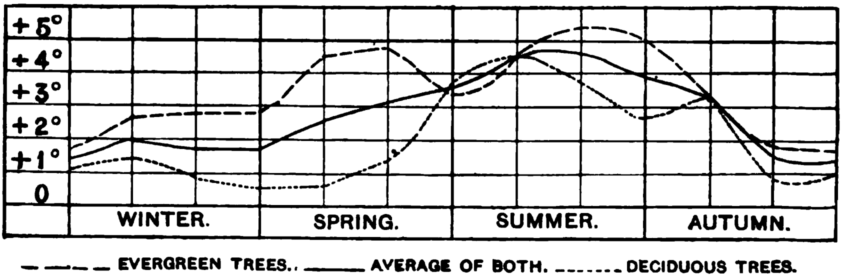


FIG. 42.—Vertical temperature gradients from observations above trees.

Fautrat's observations. They are all reversed throughout the season, and the summer gradients are about +4°. Those over evergreens are greater than those above the deciduous trees, or, perhaps more properly, the gradients decrease as we ascend above the top of the deciduous trees.

The observations under the direction of Dr. Lorenz-Liburnau at Ried were taken in the warmer months of 1888. They have been published quite recently (1890), and came under the eye of the writer only after the preceding part had been finished. They were not systematically taken, but only at such times as seemed especially suited for the study of especial features, and hence they throw light on some points which the systematic observations do not sufficiently care for. One of these is the change in temperature above and below the crown of foliage for the same station and time. Dr. Liburnau gives the following mean results from many individual observations. The plus sign indicates an increase of temperature upward, the minus a decrease.

	Change—			
	From 16.4 to 36.1 feet.		From 36.1 to 50.8 feet.	
	°F.	°C.	°F.	°C.
Morning hours	+1.08	.60	+3.24	1.80
About noon	+1.57	.87	+2.43	1.35
Afternoon	+1.40	.77	+2.16	1.20
Early night	+ .18	.10	− .11	.06
Last night and early morning	− .63	.35	− .27	.15

The station at 36.1 feet was in the crown, that at 50.8 feet above it. The distances are not great enough to get good values for the vertical gradients, but it is evident that these are very large, and greater above the crown than below.

These observations were all taken with a clear sky and calm air. Some interesting figures are also given for the differences between field and forest temperatures when the air is still and when it is in motion.

The following table gives the values of $W-O$ under these circumstances:

	Under trees, 16.4 feet (5 m.).		Tree crown, 6.1 feet (11 m.).		Above trees, 50.08 feet (15.5 m.).	
	°F.	°C.	°F.	°C.	°F.	°C.
Morning hours:						
Calm	−2.11	1.17	−1.53	.84	+2.16	1.20
Windy	−1.24	.70	+1.07	.04	+2.29	1.27
About noon:						
Calm	−2.47	1.37	− .54	.30	+2.29	1.27
Windy	−1.62	.90	+ .02	.01	+2.54	1.41
Windy	−2.02	1.12	−1.14	.63	+1230	.72
Afternoon:						
Calm	−1.37	.76	− .54	.30	+1.03	.57
Windy	−1.19	.66	−1.12	.62	-1.28	.71
First and last night hours (calm)	−2.56	1.42	−3.06	.170	−3.19	1.77

Under the crowns the temperature is lower in the forest, but above the crowns it is usually higher. The wind reduces the difference under and in the crowns, but makes little difference above them.

Putting the preceding results together, it appears that the forests reverse the vertical gradient, and that the gradient grows larger as the surface of the forest is approached. Toward the ground the change is slow; upward it is very rapid, so rapid that the special cooling effect of the forest must disappear at no great height. The surface of the surface of the forest is, meteorologically, much like the surface of the meadow or cornfield. The isothermal surface above it in sunshine is a surface of maximum temperature, as is the surface of the meadow or cornfield. From this surface the temperature decreases in both directions.

TREE TEMPERATURES.

The disturbances in temperature under trees, so far discussed, would be the same in kind if the surface covering called a forest were inorganic. They are due to the screen formed by the forest against the sun's rays and against the radiation from the soil to the sky. The kind of effect would be the same if the forest were dead, but the quantity might be quite different. The shade under a dead tree is much less than under a live one. This is due to a considerable extent to the fact that its leaves are no longer spread across the path of the sun's rays, and the heat of the latter is not so much absorbed by the evaporation of water. These, again, may be purely mechanical effects, and it is still left uncertain whether the living tree affects the temperature through its vital action; whether in the processes of life the tree does not abstract enough heat from the air, or add enough heat to the air, to be meteorologically sensible.. There is abundant reason to think that it may exert such action, because all vital processes result in the absorption or radiation of heat—and so do purely inorganic chemical processes. The tree, as an organic being, is a source as well as an absorbent of heat; the only question is whether the heat it absorbs or emits is enough in quantity to make a sensible difference in the temperature of the air. The analogy of the hot-blooded animal leads one to look first to the tree itself for a solution of this question. Even the cold-blooded animal, when of a large size, has its own temperature slightly higher than the mean temperature of the medium in which it lives. The tree is a living body. Is the same true of it?

The most elaborate series of observations of tree temperatures are those taken at Geneva for the five years 1796 to 1800. The thermometer was introduced into the trunk of a horse-chestnut tree to the depth of 6 inches, or about half of the way to the heart. The temperatures were read three times daily (sunrise, 2 p. m., and sunset), and observations were also taken at the same hours in the air and at several depths in the soil. In Fig. 43 is given a graphical representation of the mean monthly temperature, for the tree (unbroken line), for the air (broken line), and for the soil at the depth of 4¼ feet (dotted line). The straight lines across the diagram horizontally represent the mean annual temperatures for these three positions respectively. It appears that the mean temperature of the tree is lower than that of the air (by 0°.3), and still more so than that of the soil at the depth of 4 feet (by −1 .7).

The results are not easy to interpret. A part of the difference is probably due to a retardation of diurnal maxima and minima in the tree. M. Becquerel found this retardation very marked, but his observations were of such a kind that they can not be satisfactorily tabulated. He found that in small branches the summer diurnal maximum was retarded by two or three hours, while for larger ones it might be twice this. This being the case, the daily observations would not fall at the same parts of the daily curve of temperature, and whether the correction to be applied to bring them to a comparative condition should be positive, negative, or zero would depend on the hours used and on the retardation in the tree. The differences shown in Fig. 43 are, therefore, not necessarily the true differences, and with the proper corrections many of the irregularities of the curve would probably disappear. The curve, however, indicates that the tree is relatively warmer in early spring and late summer and the opposite between these dates, and also that the summer maximum is retarded as compared with that of the air.

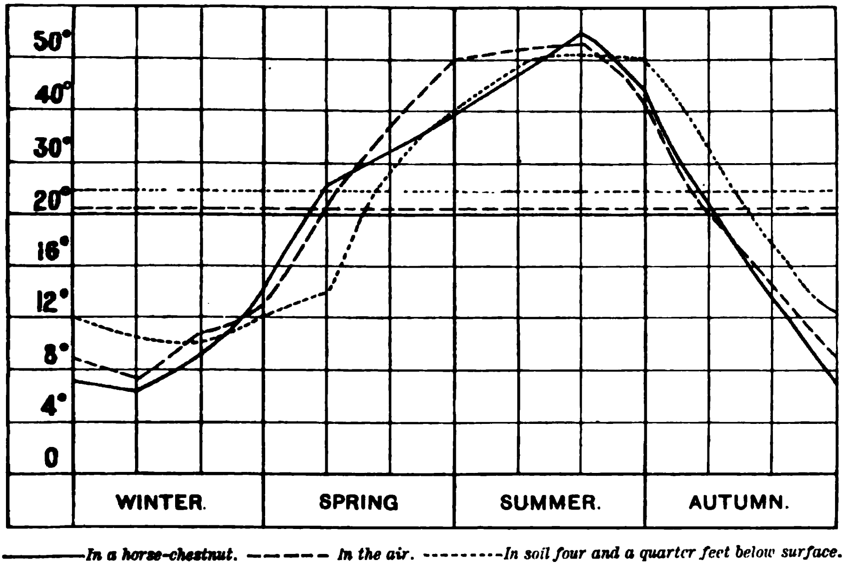
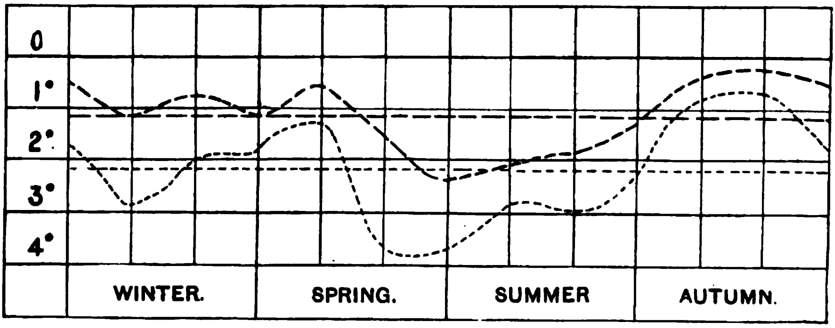


FIG. 43.—Tree temperature—Geneva observations.

The trunk of the tree is so constructed as to be a very poor conductor of heat. The wood itself is a bad conductor; the tissue is filled with air or sap, both bad conductors; and it is protected by a layer of bark which is an especially poor conductor. All these would tend to prevent the access of heat to the interior of the tree and to prevent its exit when there.

These conditions would explain the retardation of the maximum in trees but would not explain the lower mean temperature nor relatively low temperature of winter. Some light may be thrown on their condition by the values of the differences of temperature between tree and air surrounding it $(T - W)$. These observations were not made in the German service but were in the Bavarian. It is necessary, therefore, to depend here on the much shorter series of published observations of the latter service. Observations of the temperature of the tree were taken at the base and in the crown. The thermometer was always introduced to the heart. For the stations at the base this distance varied from 4 inches to 11.2 inches, averaging 6.3 Paris inches (170 mm.). The observations in the crown were made at an average height of 31.4 feet (varying from 20 to 46). The depth of the thermometers varied from 2.7 inches (73 mm.), to 8.5 inches (230 mm.), averaging 4.3 Paris inches (116 mm.). The number of trees on which observations were made through the year was eight—five evergreen and three deciduous. The results are represented in Fig. 44, the broken line showing the tree-crown observations, and the dotted line those near the base. The straight lines, parallel to the zero line, represent the corresponding mean values. While in Fig. 43 the mean temperatures are used, in Fig. 44 the monthly values of $T - W$ are shown.



——— *In tree crown. Average depth 4.3 inches.* --------- *In tree base. Average depth 6.3 inches.*

FIG. 44.—Temperature differences between tree and air.

In the arrangement of each one of the curved lines in Fig. 44 about its mean value, the corresponding straight line, there is nothing but what might be expected in observations in the interior of any inorganic mass, such as a rock, a mass of masonry, or a dead tree. In fact, except for certain irregularities, which are probably due to the shortness of the series of observations, the curves are much like the value of

W—*O* for soil temperatures. The tree, like the soil, is warmer in winter and cooler in summer than the mean value for *W*—*O*. It is also noteworthy that for the smaller trunks and branches the variations from air temperature, and the variations from its own mean, are smaller, exactly as would be the case with any inorganic body.

In short, the variations of temperatures correspond to the variations of temperature in inorganic bodies of similar character and similarly placed. In fact, Bravais, in winter observations at Bossekop, Lapland, found the temperatures in a live and dead tree to be practically the same.

It only remains to discuss the average lower temperature in trees. In Dr. Ebermayer's tables, this reduction of temperature at the base of trees as compared with air is 2°.2, while at the crown, with an average diameter of limb two-thirds as great, it was 1°.2. This reduction may be due to the temperatures of the water taken from the ground. When the sap flows most freely—in spring and early summer—the soil is cooler than the air and the water drawn from the soil must have its temperature. The tree is so thoroughly protected from the conduction of heat that this temperature must change but slowly as the sap rises. It must give a lower temperature to the interior of the tree and this lowers the annual mean. At the same time, for reasons to be given in the next section, the return sap is probably also cooled to some degree, so that all the water circulating in the tree is, in the warm season at least, cooler than the air.

The foliage seems especially arranged for the exchange of heat. Its surface is very large for its mass, and it is so exposed to the open air, to the sky, and to the sun's rays that it is adapted to receive and part with heat easily and quickly. The temperature of leaves considered as purely inorganic bodies should, therefore, be lower than that of the air at minimum, and higher at maximum. There seem to be no systematic observations on the temperatures of foliage, but botanists have taken a good many occasional observations which confirm the statement just made. The temperature of the leaves falls decidedly lower than that of the air on clear summer nights, the difference being generally several degrees and sometimes reaching eight or ten. On the other hand, this temperature rises in the sunshine to several, and occasionally to many, degrees of temperature higher than the air around; in other words, the maximum temperature of leaves in sunshine is higher than that of the air, while the minimum temperature in clear nights is lower than that of the air. A leafy branch with the cut end in water and exposed to the sunshine has been found to be cooler than one not in water, suggesting that the average temperature of foliage is on the whole lower than that of the air about it.

VEGETATION AND AIR TEMPERATURES.

It appears from the preceding section that the tree shows, of itself by its own action, no sign of warming the air and but little sign of cooling it. Systematic observations show this to be true of the framework of the tree, but no observations have been taken for the foliage and other exterior parts—the parts where most of the vital activity of the tree takes place. The great volume of chemical and physical changes which are produced here and which result in the growth of the tree and the formation of its fruits make it an open question (not yet decided by direct observations, which are not easily instituted) whether the tree does not affect temperature sensibly. So far as any observations go—those in the tree-crown for instance—they show little clear evidence of such a meteorological effect, but it will be of interest to see what can be concluded theoretically. The changes which take place at the leaf-surface, due to vital activity, are produced by the trees in common with the other and lower forms of vegetation and consequently the problem to be solved is double, namely: Do the vital processes of vegetation, in which heat is utilized or given off, produce a sensible effect on air temperatures, and is the effect, if any, different for trees and for meadows, mixed growths, or crops?

Vegetation has a complicated relation to heat in the various organic processes. In the transpiration of water it utilizes large quantities of heat, changing it from that sensible in temperature to the work of sustaining the water in a condition of vapor. This latent heat becomes again sensible when the water is condensed, but this may occur at a distance from the place where the water is taken up. By unlocking the combination of carbon and oxygen in carbonic acid, using the carbon and rejecting the oxygen, it reverses the action of combustion and so takes up heat. On the other hand, in the various processes in which oxygen is combined, it performs a process analogous to combustion and gives out heat. This process is sometimes so active (as in the germination of some seeds and the flowering of some plants) that the temperature of the parts is raised several degrees above that of the outside air, and it is sensibly warm to the hand. There are other more complicated processes going on in the plant, the relations of which to heat can not be foretold.

The quantity of heat used in these processes varies greatly with the season, the temperature, the condition of the plant, and so on. It can be ascertained only approximately even in the processes best understood. Yet the problem has so many features of interest that even such an approximate solution is desirable. For instance, the German forester Ney has attempted to show that the unseasonable frosts of mid-May in central Europe are due to the amounts of heat absorbed by plants at that season.

The transpiration of water by the plant is a vital process which needs the stimulus of the sun's rays; it takes place in the green parts only, and is especially active when these parts are young. It is the process by which the plant gets rid of the surplus water after having drawn it from the soil in order to extract from it the nutriment which is present in only a very highly attenuated solution. Botanists have made many measurements of its amount and their results are extremely varied, due partly to the fact that this function varies much naturally, and still more perhaps to the fact that the experiments are generally made under conditions which are not natural to the plant. Sachs says that it is no rarity for a tolerably vigorous tobacco plant at the time of flowering, or a sunflower of the height of a man, or a gourd plant with from fifteen to twenty large leaves, to transpire from one to two pints of water on a warm July day; and, so far as may be judged by the use of branches with the cut end in water, it may be believed that large fruit trees, oaks or poplars absorb, transport through their stems, and transpire from the leaves, ten to twenty or more gallons of water daily. He also quotes Haberlandt to show that the amount transpired by a stalk of Indian corn, in its season of 173 days, is 3 gallons; by a stalk of hemp, in 140 days, is 6 gallons; by a sunflower plant, in 140 days, is 14½ gallons.

It is not generally practicable to compare the transpiration with known meteorological phenomena, such as evaporation from a water surface, or from the soil, or the precipitation, but some such comparisons have been made. For instance, comparing the leaf surface to an equivalent water surface, Unger makes transpiration from the former 0.33 of the evaporation from the latter; Sachs for white poplar 0.36, for the sunflower 0.42. Comparisons have also been made between the transpiration from plants and the evaporation from the surface over which the plants stand. Schleiden thought that the transpiration from the forest was three times that of a water surface equal to the territory covered by the forest. Schübler thought it only a quarter; and Pfaff, who studied a solitary oak in a garden, found that it varied from 0.87 to 1.58. Comparing the transpiration of plants with the evaporation from the bare soil which would be covered by them, Hartig thought the transpiration of a forest less, Schübler found it 0.6 for the forest and 3.0 to 5.0 for sod. Marié-Davy found it, for firs 1.18, for beeches 1.32, for sod 1.86. As to the influence of sunlight, Vines quotes from Wiesner, who carried on his observations with special precautions to prevent influence from other stimuli of the transpiration. The results are given in the following small table, in which the evaporation in full sunlight is taken as unity.

Plant	Transpiration in sun.	In diffused daylight.	In darkness.
The common broom	1.00	0.40	0.37
Lily (*L. croceum*)	1.00	0.52	0.33
Bushy mallow	1.00	0.40	0.33
Indian corn	1.00	0.12	0.15
Means	1.00	0.36	0.27

From this it appears that it is the direct sun's rays that most promote transpiration. When in diffused light the plant transpires only a third as much, and in darkness only a quarter. The application of this to forests is evident, because there at any time of day a considerable part of the foliage is in shade.

The estimates of transpiration are very numerous and it is not easy to get from them an estimate of the amount for plants in terms of evaporation or precipitation. In the following table those have been selected which were most easily expressed in terms of quantities observed meteorologically. The duration of the active season was taken into account in each case.

Observer.	Plant.	Transpiration expressed as rainfall equivalent in inches.				Authority.
		Daily.		Annual.		
		Inches.	*Mm.*	*Inches.*	*Mm.*	
Hales	Sunflower	0.13	3.30	15.2	381	Embermayer.
	Cabbage	0.12	3.05	14.4	366	Do.
	Grapevine	0.03	.76	4	101	Do.
	Hop	0.05	1.27	5.6	142	Do.
Schleiden	Clover and oats	0.11	2.79	13.6	345	Do.
Vogel	4 years beeches	0.003	.076	0.43	11	Do.
	4 years firs	0.002	.051	0.28	7	Do.
	Wheat field	0.62	15.75	4.4	112	Do.
	Barley field	0.56	14.22	3.9	99	Do.
Hartig	24 years mixed forest	0.021	.533	3.8	96.5	Do.
Pfaff	Oak	0.21	5.33	193.2 (?)		Austrian Met. Journal.
Höhnel	115 years beeches	0.05	1.27	9.2	233	Sachs.
Schübler	Low spear grass	0.08	2.03	14	355	Duchartre.
Haberlandt	Oats	0.13	3.30	9.1	231	Do.
	Barley	0.07	1.78	4.9	124	Do.

The best that can be done with these very variable measures is probably to take a mean of the values of Hartig and Höhnel. This gives the transpiration of the forest as 6.5 inches (165 m.) for central Europe, or about one quarter of the precipitation. That this is not much too large is indicated by Pfaff's results, which appear to be excessive, and that it is not much too small is indicated by those of Vogel.

The most elaborate investigations on transpiration of forest trees were made by F. B. Höhnel, and since a discussion of these appears in the report of the chief of the forestry division (Mr. B. E. Fernow) for 1889, I quote his language on this subject:

> The quality of water so used is as variable as the amount of precipitation, and in fact within certain limits depends largely upon it. That is to say, a plant will transpire in proportion to the amount of water which is at its disposal. Transpiration is also dependent on the stage of development of the plant, on the nature of its leaves and amount of its foliage, on temperature, humidity, and circulation of the air, on intensity of the sunlight, and on temperature and structure of the soil and on other meteorological conditions. Rain and dew reduce transpiration, wind increases it. The amount of transpiration depends considerably upon the thickness of the leaves, therefore the surface of the foliage is not a reliable measure, but it should be compared with the weight.
>
> With so many factors to vary them the values which may be given for the amount of transpiration of various kinds of trees can only be approximations of its range

within wide limits. All the figures which have been published, based upon calculations or experiments in the laboratory, are useless for practical purposes. Especially do those figures which represent the requirement of the plant as exceeding the amount of precipitations, exhibit on simple reflection, their absurdity.

If the requirement per acre is considered, the density of the growth of plants must also be taken into account.

The first careful and comprehensive investigations into the water requirements of forest trees were made by the Austrian forest experiment stations in 1878 (F. B. Höhnel), and full tables of the results obtained can be found in the records of those stations.

An average of the many figures there presented would make the amount of transpiration per 100 grams of dry weight of leaves in conifers 4,778 to 4,990 grams of water, in deciduous-leaved trees 44,472 to 49,553 grams of water. That is to say, the deciduous trees transpired about ten times as much as the conifers, and comparing the two extremes of transpiration, the deciduous tree with the highest rate of transpiration utilized twenty-three times more water than the coniferous tree with the lowest rate. Ash, birch, and linden were found to be the most vigorous transpirers, oaks and maples transpiring much less. Curiously enough, while in the conifers shade reduced the transpiration considerably, in the deciduous trees it had the opposite effect.

During the period of vegetation the following varieties transpired per pound dry weight of leaves:

	Pounds of water.
Birch and Linden	600–700
Ash	500–600
Beech	450–500
Maple	400–450
Oaks	200–300
Spruce and Scotch Pine	50–70
Fir	30–40
Black Pine	30–40

The next season, which was more favorable to transpiration, the amounts were larger; the deciduous trees transpiring from 500 to 1,000, the coniferous from 75 to 200 pounds, or in the proportion of one to six.

The following actual amounts transpired per 100 grams of dry leaves during the third season (1880), will show the relative position of the various species (European):

	Kilograms.		Kilograms.
Ash	101,850	Scotch Pine	12,105
Birch	91,800	Fir	9,380
Beech	91,380	Austrian Pine	7,005
Hornbeam	87,170	Aspen	95,970
Elm	82,280	Alder	93,300
Maple (*A. campestre*)	70,380	Linden	88,340
Norway Maple (*A. platanoides*)	61,180	Larch	125,600
Oak (*Q. robur*)	69,150	Average deciduous trees	82,520
Oak (*Q. Cerris*)	49,220	Average conifers	11,307
Norway Spruce	14,020		

The variability of transpiration from day to day is of wide range; a birch standing in the open and found to have 200,000 leaves was calculated to have transpired on hot summer days 700 to 900 pounds, while on other days its exhalations were probably not more than 18 to 20 pounds.

A fifty to sixty year old beech was found to have 35,000 leaves, with a dry weight of 9.86 pounds; a transpiration at the rate of 400 pounds per pound during the period of vegetation would make the total transpiration 3,944 pounds per tree (about 22 pounds daily); and since 500 such trees may stand on 1 acre, the transpiration per acre would amount to 1,972,000 pounds, while the precipation during the same period would be 2,700,000 pounds.

The transpiration of a thirty-five-year-old beech with thinner leaves, of which there were 3,000, with a dry weight of 0.79 pounds, would under the same conditions transpire 470 pounds per 1 pound of foliage, or 373 pounds per tree (about 2½ pounds per day from June to November); and since about 1,600 such might be found on an acre, the total transpiration might amount to 596,800 pounds per acre, or considerably less than the amount of rain-fall.

Calculated for summer months during June, July, and August alone, the requirement of the two beech growths was 20,000 and 5,000 pounds per day an acre respectively. Conifers, as was stated, transpire one-sixth to one-tenth of the amount which is needed by deciduous trees.

The amounts transpired by agricultural crops and other low vegetation, weeds, etc., have been found to be considerably larger, as will be seen from the results of the latest investigations by Wollny, which I have calculated per acre to make them comparable with the foregoing results:

Agricultural crops.	Time of vegetation.	Water consumption per acre.
		Pounds.
Winter rye	Apr. 20–Aug. 3, 1879	2,590,186
Barley	do	2,720,238
Peas	do	3,144,128
Red clover (first season)	Apr. 20–Oct. 1, 1879	3,070,012
Summer rye	Apr. 20–Aug. 14, 1880	3,000,486
Oats	Apr. 20–Sept. 14, 1880	3,422,584
Beans	Apr. 20–Sept. 10, 1880	3,139,233
Red clover (second season)	Apr. 20–Oct. 1, 1880	4,109,198

I repeat again that these figures can only be very rough approximations denoting maxima of transpiration, and that the amounts transpired per acre depend largely on the amounts furnished by precipitation. Therefore our forest areas within the arid region of the country probably transpire a minimum of water, their scattered growth and their coniferous composition, with the scanty rain-fall, reducing the amounts to lowest limit.

Taking a rain-fall of 20 inches, which represents say 4,500,000 pounds of water per acre, a coniferous forest, assumed to transpire one-sixth of the amount found for the older beech-forest under most favorable conditions of precipitation, would require hardly more than 330,000 pounds (presuming the same weight of foliage), or not 8 per cent of the total precipitation. To be sure, this amount must be available during the period of vegetation.

THEORETICAL CALCULATION OF HEAT ABSORPTION.*

There is another way in which the average amount of transpiration can be approximated, perhaps more closely than by the method of direct measurement. The water transpired comes mostly, if not entirely, from the soil. On evaporating it leaves behind it the matters held in solution, a portion of which is inorganic and is that which constitutes the ash of the plant. Assuming that the absorption by the plant is not sensibly selective in the average from a large number of individuals, then a knowledge of the annual addition of inorganic material, *i. e.*, ash, to the forest, and the amount of mineral matter held in solution by the ground water will enable us to compute the amount of water which has been evaporated. The required data, particularly the latter, are often known with some exactness. Taking, with Grandeau, the average amount of ash in the plant at 5 per cent and the quantity of mineral matter in solution as two parts in ten thousand, the plant must transpire five thousand times the weight of its ash or two hundred and fifty times its own direct weight. Grandeau gives 6,497 kilograms as the annual production of a beech forest (wood and foliage), 6,442 as that of Norway spruce, and 6,420 as that of pines, for every hectare covered. These numbers multiplied by 250 would give the quantity of water transpired, which, reduced to thickness of the sheet of water over a hectare, gives the depth or rainfall equivalent. In these cases it gives 6.4, 6.3, and 6.3 inches, respectively. The numbers given by Grandeau are for central Europe, as were the preceding. The results by the two methods are 6.5 and 6.3 inches, which, by chance, are remarkably close to each other. Knowing the amount of water transpired, and the temperature at which transpiration takes place, it is easy to get the amount of heat used up in the process. The evaporation of any given weight of water would heat by 1° C. a weight of air which is $\dfrac{606.5 - 0.695t}{0.2375}$ times as great, where t is the centigrade temperature of the water evaporated. As water is 773 times as dense as air at the standard temperature (32° F.) and standard pressure (30 inches), the evaporation of a layer of water an inch thick takes up as much heat as would warm by 1° C. a layer of air of standard density and of a thickness of $\dfrac{606.5 - 0.695t}{0.2375} \times 773 =$ $(606.5-0.695t)\ 3255$ inches. For different temperatures the thickness of the layer of a homogeneous atmosphere which might be cooled 1 degree for each inch of the layer of water evaporated is as follows:

---

* The computations in this section are made on the decimal system because of its greater simplicity.

Temperature.		Thickness of air layer.
°C.	*°F.*	*Miles.*
0	32	31.1
10	50	30.8
20	68	30.4

The cooling equivalent to the annual forest growth is therefore about 6.4 times that expressed in this table and takes place through the entire season, but is greatest in late spring in sunshine, least in darkness in late summer. It acts, however, continually, and when the enormous thickness of the air layer is divided by 150 days (about the length of the active season) and this by the number of seconds in a day, the result per second does not appear so very large. As a convenient general expression it may be said that the evaporation of any depth of water would take up enough heat to cool by one degree (Fahrenheit in this case) one million times that depth or volume of air, the latter being of average temperature and density.

In calculating the effect of the breaking up of the carbonic acid, we may assume that as much heat is used as would be given out by burning the same quantity of carbon in oxygen—that is, by remaking the compound. Grandeau gives as the annual product of carbon by plants, per hectare, 3,000 kilograms for forests, 1,500 to 4,500 kilograms for open fileds, and, exceptionally, 15,000 kilograms for a field of giant maize. This is probably all derived from the carbon dioxide of the air. The burning of a kilogram of carbon produces 7,900 large calories of heat according to Andrews, or 8,080 according to Favre and Silbermann.

The large calorie is the amount of heat necessary to raise one kilogram of water 1° C. in temperature; it would warm to the same amount $1 \div 0.237 = 4.22$ kilograms, or $4.22 \times 773.3 = 3263.3$ liters of standard air. The burning of the annual carbon productions above given would warm by 1° C. the thickness of air mentioned in the following table, in which 7,900 is used as the number of calories produced by the combustion of 1 kilogram of carbon:

	Calories used per annum per hectare.	Liters of air cooled.	Thickness of air cooled.
			Miles.
Forest	23.7×10^6	77.2×10^9	5.0
Prairie	11.8×10^6 35.5×10^6	38.6×10^9 115.8×10^9	2.5 7.5
Maize	118.5×10^6	386.0×10^9	25.0

It appears that the heat absorbed by the entire carbon assimilation for a forest is only from one-fifth to one-sixth of that used in evaporating a layer of water an inch deep. As the latter is only a sixth or a seventh of the transpiration, it appears that the cooling which would be caused by the breaking up of carbonic acid, in order to form forest growth, is only from one-thirtieth to one-fortieth of that caused by the transpiration.

It is highly probable that the heat used in the former process is more or less closely made up by the heat produced in the oxidations that go on in the plant. In any case the cooling due to this source may be disregarded and only that of the transpiration be considered. It is estimated that the sun's rays, when the sun is vertical, pour out twenty-five calories per minute over each square meter of surface exposed vertically to it. Of this about 30 per cent is absorbed in passing through the atmosphere, when the sun is vertical and the sky clear, and very much more under other circumstances. The 17.5 calories, for a clear day and vertical sun, would in a single minute evaporate a layer of water 0.0011 inch think. But the transpiration is about 6.5 inches for the season of about 150 days, or 0.00003 per minute. Thus the sun's rays under these favorable circumstances pour on the surface $1\frac{1}{3}$ times as much heat as is required for evaporation. If the maximum heat of sunshine is reduced by one-half for latitude, by seven-eighths because of night and of low morning and afternoon temperatures, and again by one-half because of cloudy weather, making its average value one thirty-second that given above, yet there is more than enough over each square foot of forest to effect the transpiration.

It is only where the transpiration has been very active during the day and continues into the night that its cooling could be possibly injurious, but as the temperature cools the transpiration itself is checked, and besides the moisture which it has poured into the atmosphere serves as a screen to prevent rapid radiation from the soil, and its condensation returns some of the heat that had been taken up. There might, however, occur a combination of circumstances, very rapid transpiration during the day absorbing the sun's heat, a clear night, calm air and a low temperature from other sources coming on with the evening, when the transpiration might cause the temperature to fall below freezing. This could hardly happen, however, without a meteorological change toward cold, and this change must come on toward evening, for otherwise it would itself check the transpiration.

The combination would be more likely to occur over herbaceous growths, especially over grass and cereal crops, than over forests. Their transpiration, it appears, from the table (page 80), is decidedly greater than that of the forests, and they make rapid advances much earlier in the spring when such low temperatures are otherwise possible.

TEMPERATURES IN WOODS, GLADES, AND PLAINS.

The foliage of the trees reflects a considerable part of the solar rays which reach it, and this heat is reflected in all directions. That part which passes toward the sky is probably lost, and plays only a small part in warming the air. The part which is reflected longitudinally or at downward angles has a very favorable path for absorption by the air, more favorable in fact than that of the noonday direct rays of the sun. The absorption of this heat should occur, for the most part, in the vicinity of the forest. The temperature around the forest ought, therefore, to reach a somewhat higher maximum on sunny summer days than that of the air at some distance from the forest.

On the other hand, the surface at the stations near the forest is exposed to nocturnal radiation of heat to the sky about as freely as is the station at a distance, and, as the former is often in the lee of the forest, its air is generally more stagnant. This promotes cooling of objects at the surface of the earth, and as the station near the forest is as much exposed to celestial radiation and the relative stagnancy of the air favors this cooling, and also favors the communication of it to the adjacent air, the temperature at such stations should often fall lower than over a plain distant from woods. The forest-field or forest-glade station is, therefore, not exactly like a station in an open plain. It is likely to average a little warmer in the day and a little cooler at night, giving it a greater daily amplitude not only than that under trees, but greater, too, than that in open prairies. Whether the mean temperature would be different in the forest-field station would depend on the relative increase in maximum and minimum. If the increase in the former is greater, the forest-field station temperature would be higher than that of the prairie station; if the minima exaggeration is greater, it would be the opposite.

The phenomena mentioned above are especially noteworthy in forest glades. The horizontal reflection from the foliage comes there from all sides, and the heat rays not absorbed are reflected from the opposite side, a part to the sky, a part to the opposite side, and this reverberation of the heat makes such places oppressively hot in the early afternoon. This is well known to the hunter and to the pioneer with his little clearing in the deep woods. Again, as the closed glade is in the lee for winds from all directions, the air is always somewhat stagnant and clear weather celestial radiation must always make a lower minimum temperature than where there is free circulation of air. The field station, when there is a pair, one in the forest, the other near by in the field, must always have something of the glade character in its temperatures, and the data given at this point must be somewhat affected by it. The relations for range of temperature, as between the interior forest and its external station should show this, and the ranges should be somewhat greater than between forest and plain. Whether there is an exaggeration of the mean values of $W-O$ can only be told by observation. Fortunately the plan of the Swedish observations included and was rather devoted to this particular side of the problem. The stations were really of four kinds. The first were under woods, of which there were but three. The second were the parallel field stations for the three forest stations. These were usually located in an "endroit libre" (opening), but the distance of the forest in all directions is given, so that this means a "glade" of greater or less size. The third class were stations in "clairièré" (clearing), with the distance from woods in all directions (and not very great). Each of these also signifies a "glade," but large and unlike the preceding. It has no corresponding forest station. The fourth class comprises stations in large open places, far from forests. These are stations in the plain. This distribution of stations affords the great advantage of permitting a study of the average amount of change due to the "glade" position of a station and thus enabling us to pass from the relations between parallel stations to those between wooded and treeless districts. It has, however, the disadvantage that the stations are not strictly comparable, as in the "parallel" system, and as would be the case in the "radial" system. This difficulty can be in large part overcome by the careful selections of stations, and this Dr. Hamberg, as appears from his discussion of the Swedish results, has endeavored to make.

The deductions of Dr. Hamberg have been taken without change, except in reducing the units to the common English ones. The air observations were taken at a height of 1.8 meters (5.9 feet). The series of observations discussed for temperature are usually from three to five years' duration. The mean annual results are shown in Fig. 45. In the air temperatures the maxima are higher in the woods as compared with the glades and as compared with the plains. They are, therefore, erected above the zero line. The maxima are reduced in both cases, and they are let fall below that line. It appears at once that the mean range is larger (the total line longer) for the reduction by wood as compared with plain. If the comparison of woods with glade be $W-G$, and wood with plain $W-P$, then the following exhibits the differences:

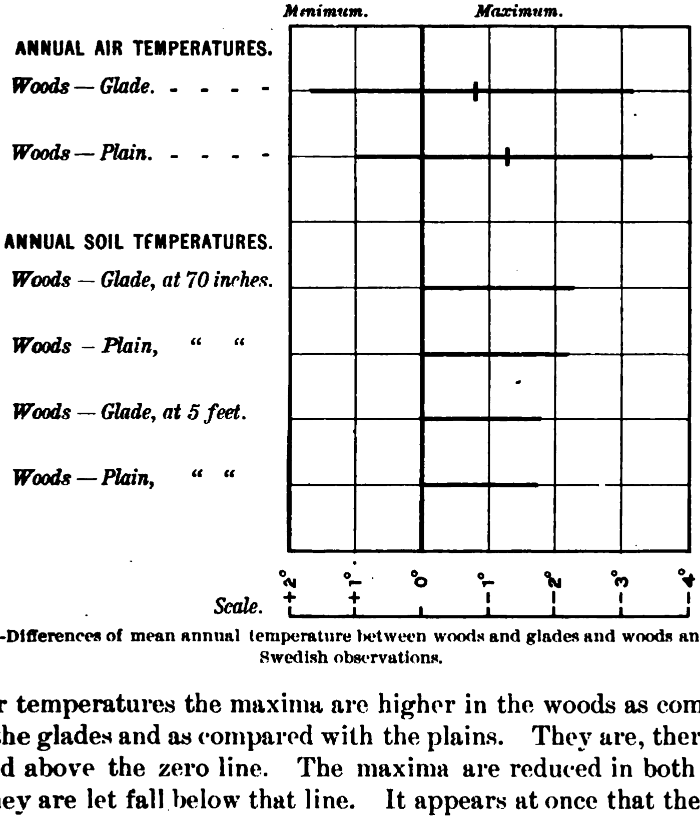


FIG. 45.—Differences of mean annual temperature between woods and glades and woods and plains, Swedish observations.

Temperature differences in woods, glades, and plains.

	W - G.	W - P.	G - P.
	Degrees	*Degrees.*	*Degrees.*
Maxima	-3.06	3.24	-0.18
Minima	+1.53	+0.99	-0.54
Mean	-0.76	-1.13	-0.36
Range	4.59	4.23	0.36

The range is exaggerated in the glade as compared with the plain by 0°.36. The minima are also exaggerated in the plain by 0°.54, but it appears that in this case the maximum is reduced.

The disappearance of this feature of glade temperatures is doubtless due to the large size of some of the glades, and also to the high latitude of the stations, giving a low latitude to the meridian sun. The relatively large reduction of the maxima causes the mean temperature of the glade to be 0°.36 lower than that of the plain. It appears, therefore, that the glade climate is by a small quantity more rigorous than the climate of open plains. The forest tends in so far to exaggerate or sharpen the diurnal changes of temperature.

Fig. 45 also shows the values of *W—G* and *W—P* for soil temperatures at the depths of 20 inches and of 5 feet. The temperatures are slightly higher under plains; *G—P* at both ends = +0°.1.

Fig. 46 shows the monthly values of *W—G*, *W—P*, and *G—P*. The stations are not necessarily the same for the three figures nor the same as for the preceding. The first curve is of the same character as the temperature figures in the preceding sections, and shows the same general features. The cooling effect is much more marked in the spring than has been the case with any examined before. The second shows an exaggeration of the features of the first, except for the line of minima, and these appear in spring and summer to be much the same in forest and plain.

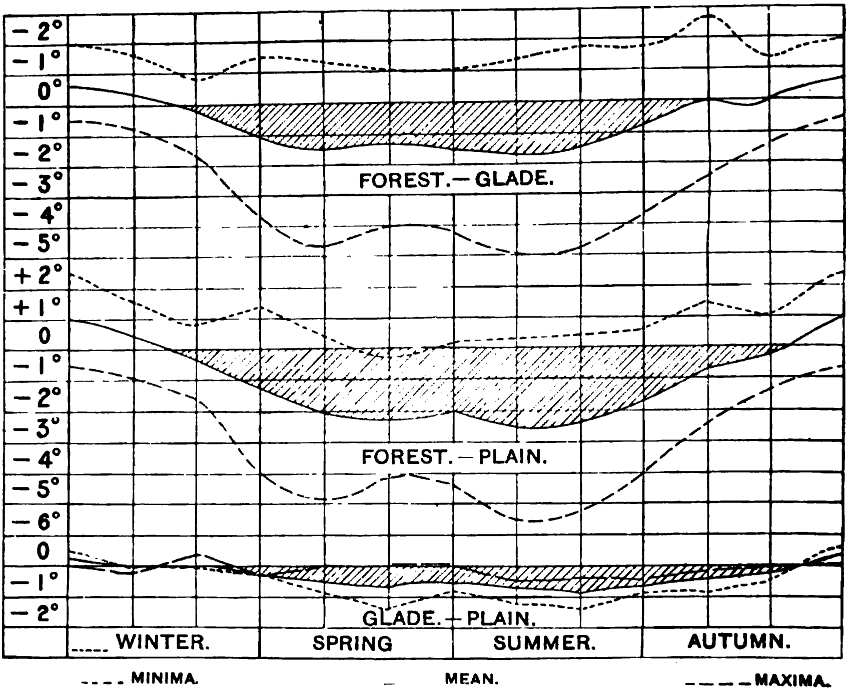


FIG. 46.—Differences of air temperature in forest, glade, and plain (Swedish).

The third figure enables us to compare the differences between glade and plain. They are small, but curious. The line for minima (dotted line) and for maxima (broken line) have changed places. The maxima are reduced generally, though slightly, in glades as compared with plain, but the minima are exaggerated by a quantity two or three times as large. The result is that the glade is cooler in mean temperature for three of the seasons, and that its diurnal amplitude is sharpened or its climate made more rigorous. In winter the advantages are with the glade, in the other seasons against it.

To bring out more clearly the advantage in range possessed by the plain over the glade, Fig. 47 has been constructed. The distance from the zero line to the first curve gives the reduction of daily amplitude in woods as compared with plains, to the second of woods as compared with glades. The distance between the lines is the difference in amplitude favorable to the plain as compared with the glade. It does not change sign during the year, and glade and plain are alike for only one month, that of July. Fig. 48 gives the temperature values of *W—G* (unbroken line) and *W—P* (broken line) for the soil at the depth of 20 inches. As is to be expected, the temperature of the glade soil is intermediate between that of the woods and that of the plain.

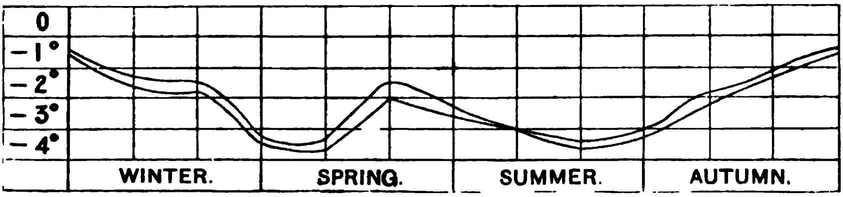


FIG. 47.—Amplitude of W—G (lower curve) and W—O (upper curve), Swedish observations.

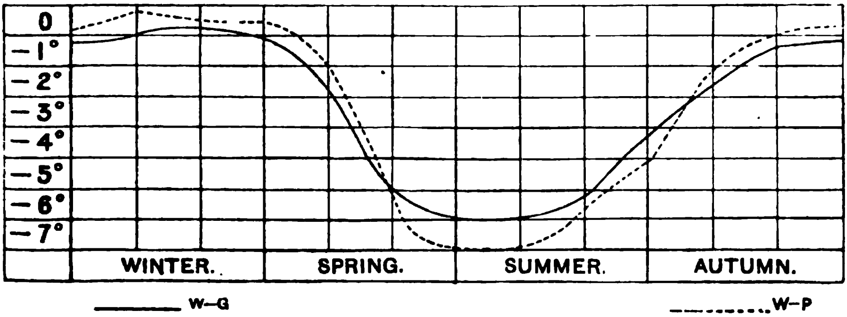


FIG. 48.—Difference of soil temperature at 20 feet in depth.

Dr. Hamberg also studied the effect of clear and cloudy weather on the differences between glade and plain. The following table gives the mean values of *G—P* for clear and cloudy weather at the three hours of daily observation. The clouds cause the temperatures at the two stations to approach the same degree, reducing *G—P* to zero:

Temperature differences in glade and plain.

	Clear.			Cloudy.		
	8 a.m.	2 p.m.	9 p.m.	8 a.m.	2 p.m.	9 p.m.
	Degrees.	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*
Winter	0	+0.9	−0.5	−0.2	0	+0.2
Spring	+0.5	+0.2	−1.4	+0.4	0	−0.2
Summer	0	0.2	−1.8	+0.2	−0.2	0
Autumn	+0.4	+0.4	−1.3	+0.4	0	0
Year	+0.2	+0.3	−1.3	+0.2	0	0

Again, Dr. Hamberg studied the relations of this difference to the direction of wind, and found the effect to be very slight, perhaps not appreciable. The horizontal reflection of the rays of heat from the foliage could cause an area of greater maxima and the shelter from the winds an area of lower maxima about a forest. The two together would cause an area of greater amplitudes or more rigorous climate, and this has been directly observed by La Cour in Denmark. Observations were taken at a series of stations at different distances from the margin of the forest, but at elevations above the sea, varying by only 10 or 12 feet. The result of twenty-four days' observation in the summer of 1867 in Jutland are given in the following table, where the corrections for differences of elevation are already made. The thermometers were arranged on a line from a northern to a southern forest:

Station.	Mean temperature.	Daily amplitude.
	Degrees.	*Degrees.*
200 feet within northern forest	56.8	9.2
At its margin	57.2	9.9
200 feet from margin	58.3	13.3
400 feet from margin	58.1	12.6
200 feet from south forest	58.3	13.8
At its margin	57.7	12.4
200 feet within it	57.2	11.0

It appears that the least amplitudes are in the forest and the greatest at something over 200 feet, not less than 400 feet, outside. In this case the highest temperatures are at the same distance. A corresponding series of observations were taken on the island of Zealand and a similar area of highest amplitudes was found.

CONCLUSIONS REGARDING TEMPERATURES WITHIN AND WITHOUT FORESTS.

This completes the review of the direct comparative observations of temperatures in woods and without. While the observations show, like all other meteorological phenomena, very great variations due to soil, topography, latitude, and many other agencies, they permit us to draw a series of conclusions which may be considered as definitely established in their general features. They are—

(1) There is one season only of marked forest action and that is the warm season. The action is most marked in the early summer months.

(2) In the forest during this season the maxima of temperatures are lowered, the minima are raised, the mean is lowered by a degree or two, and the daily range is reduced by several degrees. This action decreases slowly up to the level of the foliage, then rapidly, disappearing at a score or two of feet above the foliage.

(3) The forest litter plays an important part in preserving the temperature of the forest soil.

(4) The vertical temperature gradient through the forest is reversed; it is greatest at the level of the foliage, decreasing slowly downwards but rapidly upwards.

(5) The diurnal amplitude increases from the margin of the forest outwards to a distance of a score or so of rods, where it reaches a maximum. The amplitude is also greater in glades. Hence the extremes of temperature are exaggerated just outside the forest.

(6) As a result of the discussion of tree temperatures and the organic sources of warming and cooling in the plant, it may be added that—

(7) The changes of heat due to organic processes are not sensible except, possibly, the cooling due to transpiration. The heat used in this process is an appreciable fraction of the heat from the sun's rays and the cooling due to it may lower to the point of frost a temperature already falling from general meteorological causes.

TEMPERATURES IN WOODED AND TREELESS TERRITORIES.

In passing to the subject of temperatures and forests in its broader aspect, namely, in so far as it relates to differences in wooded and treeless territories that are situated widely apart, the strict comparability of the stations is lost. The stations to be compared are distant from each other at different elevations above sea level, in different latitudes, and, possibly, members of different meteorological services, with all the differences in instruments and methods which that implies. These differences in the stations can not be so perfectly neutralized by applying corrections to the observations as entirely to satisfy the critical reader, because the corrections are themselves uncertain and they often surpass in quantity (for instance, the corrections for altitude) the amount of change which forest might be expected to make. Besides, it is often impossible to say when a difference is found that this is due to the forests. It may be due to other causes, for instance, the coolness of evaporation in regions of heavy rainfall, and the existence of the forest may be due to the very difference found. These difficulties may be evaded more or less completely in certain definite cases, and it is the published cases of this sort which will now be given. The case of Vienna and its surroundings, discussed by Dr. Hann, is one of the most satisfactory. It is the case of the temperatures in open fields about Vienna and in the Vienna forest. The elevations vary by less than 200 feet and the observations are corrected for the variation. The mean temperatures about Vienna are obtained from four stations.

Stations near Vienna.	Latitude.	Elevation.	January.	April.	July.	October.	Year.
	48+	*Feet.*	°	°	°	°	°
Hohe Warte	15′	663	29.5	49.3	67.8	50.2	48.7
Neue Sternwarte	13′.9	847	29.3	49.1	67.6	50.2	48.6
Mödling	5′	787	30	49.6	68.4	50.7	49.3
Perchtoldsdorf	7′	853	29.8	49.3	68.9	50.7	49.3

The best forest station for the comparison is Hadersdorf, 18 miles southwest of the Hohe Warte, and its altitude differs from this by 92 feet. If the second or cooler pair of stations in open country near Vienna be represented by *A*, the first or cooler by *B*, and the observations at Hadersdorf by *C*, the comparison stands as in the following table:

	Latitude.		January.	April.	July.	October.	Year.
	°	′	°	°	°	°	°
A	48	6	29.9	49.4	68.7	50.7	49.3
B	48	14.5	29.4	49.2	67.7	50.2	48.6
C	48	13	28.6	47.7	65.5	48.7	47.1
C-*B*			− 0.8	− 1.5	− 2.2	- 1.5	− 1.5

This table shows that there is an appreciable cooling in the Vienna forest and that this is greatest in summer and least in winter. The forest consists of beech trees only.

A detailed comparison also brings out a curious fact. The temperature in the forest region is nearer that in the open region at the 2 p. m. observations than for that at the 9 p. m. observations. The monthly means for the years 1875–1884 give the Hadersdorf temperature as 0°.2 higher to 0°.7 lower than the Hohe Warte temperature at 9 p. m., 1°.1 lower to 4°.5 lower, the difference being greatest in the summer months. The 7 a. m. observations are intermediate, varying from 1°.1 to 2°.2 lower at Hadersdorf. The explanation of this is probably to be found in the fact that the station at Hadersdorf is, in some sort, a glade station. The thermometer is not under trees, but is on the north side of a building under the usual Austrian shelter. As already pointed out, the glade has a greater range than the open field, and its maxima and minima must fall at about the same hour of the day. If the 2 p. m. observations were deferred an hour or two, the temperatures at Hadersdorf would probably be higher than at Hohe Warte.

The stations in forest regions used in making these general comparisons are not likely to be under trees. They are the ordinary meteorological stations, and while in wooded territories, they could not properly be established under the shelter of the compact foliage of a forest.

They are generally in larger or smaller open places, generally on the north side of the building. They are, therefore, often of the nature of "glade" stations. While they will not show the relation between the interior air of forests and the surface air of prairies, they will bear on the practically more interesting question of the differences between these spots of a wooded region which are occupied by man and the prairie or plain, or the treeless region. The results, however, will differ somewhat from those obtained by a system of parallel stations.

The meteorologist who has published the most elaborate study of this subject is Dr. Woeikoff, who has devoted a chapter to it in his book on the climates of the earth. A striking case given by him in some detail is that of northern India. April to July are here the hot months. From July on the heat is tempered by abundant rains. The temperatures are compared, for the hot months, over a territory that includes the three different characters of treeless, transition, and wooded. In the first the vegetation is already burnt up by March, except for small stretches where irrigation is practiced. The third is the great forest region of the middle course of the Brahmaputra and its southern tributaries, where the surface is covered with the densest forests, and the openings are little else than islands in the sea of forest. The transition region lies over the delta of the Ganges and northward and has no extended forests, but groves and scattered trees and abundance of bamboos. The table which follows is Dr. Woeikoff's, except that for the most of the stations the temperatures have been taken from a later publication, that of Mr. Blanford's "Climates of India."

Station.				Mean temperature.						Mean maxima.	
Name.	Lat.	Alt.	Distance from sea.	Year.	Apr.	May.	June.	July.	Dec.	Year.	Apr. and May.
Open territory.	°	*Feet.*	*Miles.*	°	°	°	°	°	°	°	°
Agra	27	555	679	79	88	94	95	87	62	116	106
Lucknow	27	369	533	78	87	92	92	86	61	114	104
Allahabad	25.5	307	432	78	88	92	91	85	61	116	106
Patna	25.5	183	303	78	87	89	88	85	62	110	101
Burhanpur	24	66	161	78	85	85	84	83	66	109	101
Intermediate territory.											
Sangod	21.5	26	0	79	82	85	85	83	67	....	....
Durbunga	26	116	337	77	84	85	85	84	63	105	96
Purneah	26	125	283	77	84	83	84	84	63	105	98
Forest territory.											
Silchar	25	104	131	76	78	80	82	82	66	99	87
Goalpara	26	384	249	76	78	78	80	81	65	....	....
Sibsagar	27	333	364	73	74	78	83	84	61	99	86

The fall of the temperatures in the hot months as the forest is reached is very noticeable, and it is still more so in the reduction of the maxima. The cooling in the forest region even appears to surpass that due to proximity to the sea. It is true that this difference in temperature may be in part due, as has been claimed, to other causes. The temperature in latitudes 20° to 30° N. seems to fall slowly from Western India to China and Tonquin, but Dr. Woeikoff finds that it rises in the east, in the hot season, where there are extensive treeless regions, and instances Hanoi, in 21° N., where the annual temperature is 75°.6, May 83°.8, June 88°.2, July 86°.9.

Dr. Woeikoff also gives series of temperatures near parellels of latitudes across Europe and into Asia. A correction of 0°.9 is made for each degree of latitude, and of 1°.3 for each 100 meters of elevation. All temperatures are reduced to a uniform elevation of 200 meters (656 feet). The order is always from west to east.

Mean temperatures for July on the parallel of 52° N.

	Degrees.		Degrees.
Valentia	57.6	Orel and Kursk	67.6
Leipsic	62.6	Poljänki	65.7
Warsaw	64.7	Orenburg	69.1
Tschemigow	65.1	Akmollinsk	70

The mean temperature is lowest on the Atlantic coast. It rises up to Poland by seven degrees, then remains steady over the forests of the Bug and Dneiper, then rises over the black-earth region of Central Russia with extensive cultivation (Orel and Kursk), falls again in the forests over the sources of the Sura (Poljänki), to become again higher over the Kirghiz steppes.

July mean temperature along 50° N.

	Degrees.		Degrees.
Guernsey	59.5	Troppau	68
Brussels	62.6	Arvavarallja (Carpathians)	64.2
Würzburg	68	Lirow (Lemberg)	65.5
Promenhof (N. W. Bohemia)	64.4	Kieft	66.2
Prague	68	Charkow	68.4
Hochwald	63.9	Semipalatinsk	72.7

The temperature increases rapidly to the Main valley, then rises and falls over the forests of Bohemia and the Carpathians, becoming hardly higher at Charkow, where there remains some forest, than at Würzburg. Eastward from here it rises rapidly.

July mean temperatures along 48° N.

	Degrees.		Degrees.
Brest	62.2	Bistnitz (Transylvania)	68
Versailles	65.5	Czernowitz	68.9
Carlsruhe	66.6	Ekaterinoslaff	71.6
Vienna	67.8	Lugau	72.5
Debreczin (Hungary)	70.7	Irgis (steppes)	75.6
Rosenau (Hungary)	68.9		

Here the rise is about eight degrees from the Atlantic to the prairies of Hungary (Debreczin). It is cooler in Eastern Hungary and in Transylvania, where there is yet much forest. Czernowitz is near the

South Russia steppes, but it escapes their warming influence by the beech forests around it. This is the eastern limit of the beeches.

July mean temperatures on 46° N.

	Degrees.		Degrees.
La Rochelle	66.7	Oravicza Mountains, Southeast Hungary	67.5
Milan	62.9	Pojana Ruska (Hungary)	67.8
Trieste	72.7	Odessa	71.2
Agrau	71.1	Chersson	72.5
Szegedin (Hungarian prairies)	71.6	Astrakan	75.6
Arad (Hungarian prairies)	73		
Raimsk and Kasalinsk	76.1		

The high temperature of Trieste agrees well with its bare and burnt surroundings. In Croatia, far from the sea and where there are woods in the plain, it is cooler, warmer again in the Hungarian prairies, but 5° or 6° cooler in southern Hungary and Banat, where the vegetation is luxuriant.

July mean temperatures along 42° N.

	Degrees.		Degrees.
Oporto	67.6	Poti	70.9
Rome	75.2	Tiflis	78.8
Ragusa	74.5	Kutais	73

Poti is in the midst of the swamps and forests of Mingrelia and its temperature is 4° lower than in the Dalmatian towns on the Adriatic. Even Kutais is cooler than Ragusa, though the former lies far in the interior and the forests have been cut freely in its vicinity.

July mean temperatures along 38° N.

	Degrees.		Degrees.
Lisbon	70.5	Smyrna	77.9
Campo Major	76.3	Lenkorau	74.7
Palermo	76.5	Krasnoodsk	82
Athens	76.2		

The low temperature of Lenkorau is especially noteworthy because it is deep in the interior of a continent and the cloudiness and rainfall are light. Yet in the vicinity are extended forests with luxuriant vegetation. It is on the Black Sea, while Poti is on the Caspian. Near both are extensive forests. If the July temperature is reduced to 42° N. but not corrected for elevation, it proves to be 73°.6, only 0°.4 higher than that of Poti.

Dr. Woeikoff also calls attention to the remarkable relations of Bosnia, Herzegovina, and Dalmatia, along latitude 44° N. The temperatures are here the annual means.

	Degrees.		Degrees.
Banjatella, Bosnia	70.3	Klissa, Herzegovina	74.8
Dolnja Tusla, Bosnia	68.2	Mostar, Herzegovina	76.1
Trawnik, Bosnia	70.3	Knin, Dalmatia	73.6
Serajewo, Bosnia	69.3	Lissa, Dalmatia	72.3

Here it appears that the densely wooded Bosnia is 5° or 6° cooler than rocky, nearly treeless Herzegovina, and even cooler by 2° or more than the small island of Lissa, which is exposed to the full influence of the Adriatic.

All this goes to show that in the western part of the Old World the presence of large forests has a very sensible influence on the temperature, so much so that the gradual rise of temperature from west to east is almost invariably broken by it.

Comparisons similar to those of Dr. Woeikoff can be made along parallels in the United States with results similar in character, but not so striking in quantity.

The writer has made this comparison for the parallels which follow. The data are taken from the annual reports of the Chief Signal Officer.* They are reduced to a common elevation of 1,000 feet above sea level. No reduction is made for latitude, but the stations used are selected not far to the north or south of the chosen latitude.

Temperatures along parallel 38° N.

	Latitude N.	Altitude.	Annual mean temperature.	June temperatures.			December temperatures.		
				Mean.	Max.	Min.	Mean.	Max.	Min.
	°	*Feet.*	°	°	°	°	°	°	°
Lynchburg	37	652	57	73	82	64	40	47	30
Louisville	38	551	56	72	82	64	38	45	30
Cairo	37	359	56	74	81	66	37	44	29
St. Louis	39	571	54	72	82	64	33	42	27
Leavenworth	39	842	53	73	83	63	30	40	24
Dodge City	38	2,517	56	79	91	67	34	47	26
Las Animas	38	3,899	58	80	96	66	35	52	24

Leavenworth lies near the margin of the wooded and treeless district, but in no case are the woods heavy and unbroken. The mean temperatures show no unmistakable effect of the woods, but there is an evident difference in the December temperatures, and a still more marked difference in those of June. The difference is most marked in the extremes, as was to be expected. This is most clearly shown in the mean amplitudes obtained by taking the minimum from the maximum. The amplitudes for December at stations in the order given in the above table are 17°, 15°, 15°, 15°, | 16°, | 21°, 28°. The change at the edge of the plains is very noticeable. For June the amplitudes are 18°, 18°, 15°, 18°, | 20°, | 24°, 30°, with the same change as before.

This comparison is not entirely convincing of the effects of forests, because with the change of condition as to trees there is a large change of elevation, so large that the correction for it surpasses by far the difference which may be expected from the action of forests. This difficulty can not be entirely overcome in the American stations, for the plains form an interior table-land, but individual pairs of stations can be selected, otherwise suitable and where the differences of elevation are less marked. Such are given in the accompanying table. One station is in the wooded district, the other in the plains, and they have been selected with reference to being in the same latitude, to being as near the margin as possible, and to having at the same time only moderate differences of elevation.

---

*1885, pp. 82–84, and 1886, pp. 408–411.

Mean temperature for stations in pairs.

	Lat. N.	Altitude.	Annual mean temperature.	June temperatures.			December temperatures.		
				Mean.	Max.	Min.	Mean.	Max.	Min.
	°	Feet.	°	°	°	°	°	°	°
Little Rock	34.7	288	60.0	75.3	85.7	67.4	43.4	50.9	35.2
Fort Sill	34.7	1,200	60.8	79.1	90.5	67.8	38.2	53.1	37.1
Fort Smith	35.4	451	57.7	75.0	87.5	65.7	39.2	50.8	30.6
Fort Elliott	35.5	2,650	60.7	82.1	92.3	67.7	38.1	52.7	28.3
Davenport	41.5	615	49.1	68.4	76.6	58.9	26.9	34.9	19.3
North Platte	41.1	2,841	53.3	75.6	87.6	64.9	28.1	42.9	20.8
Moorhead	46.9	926	36.4	64.5	75.6	52.2	9.5	20.1	0.4
Bismarck	46.8	1,694	41.2	67.9	78.6	55.6	11.9	26.6	6.7
St. Vincent	48.9	804	32.6	61.4	73.1	48.8	4.0	14.7	5.8
Fort Assinniboine	48.5	2,720	45.8	69.9	82.5	58.4	21.5	32.8	14.1

The mean annual temperatures are persistently lower at that station of the pair which is situated in the wooded district. The same is true of the mean June temperature, while it is reversed for the December one. The maxima are lower at the stations in the wooded area and also, generally, the minima. The mean monthly amplitudes for each pair for June are 18°.3 to 22°.7, 21°.8 to 24°.6, 17°.7 to 22°.7, 23°.4 to 23°.0, 24°.3 to 24°.1; for December they are 15°.7 to 16°.0, 20°.2 to 24°.4, 15°.6 to 22°.1, 19°.7 to 19°.9, 20°.5 to 18°.7. They are generally larger at the station on the plains—always so at the lower latitudes.

It appears, therefore, that wooded districts have an advantage in temperatures over treeless areas. The forests lower the mean temperature slightly and also cut down the range.

There has been much discussion over evidence of change of temperature at individual stations, or over more extensive areas, which might accompany changes in the quantity or distribution of the forests. The general opinion is that the data are not sufficient to give satisfactory conclusions. To be sure of a change, one must be sure of a definite and marked change in the amount of forests and must also be sure of the temperatures before and after the change. The first requirement is not without its difficulties, and the second is usually impossible. The early observations, if any were taken, are always defective in methods, instruments, and the care given to them. A variation in the exposure of the thermometer alone might cause a greater difference of mean temperature than we would expect to find between forests and prairies.

RELATION OF EVAPORATION TO FORESTS.

The amount of evaporation depends especially on the temperature, the wind, and the amount of vapor already present in the air. The first two are much changed by the presence of the forest, and it is to be expected that the evaporation in and about woods would show some peculiarities. The evaporation varies very much also with the character of the surface from which it proceeds. Some surface must, therefore, be taken as a standard for evaporations, and the measurements be made with reference to this. There is considerable variation in the standard surface selected, but in the German service it is that of water. The reductions have been made, in this section, to terms of evaporation from a water surface. At the same time, since the evaporation is chiefly of meteorological interest because of its relations to precipitation, the amount of the latter is also included in the comparisons. The observations were carried on in the open fields and in the forest. The instrument employed is described on page 39.

Fig. 49 exhibits the comparison of the annual evaporation in fields (*E O*) and woods (*E W*) with the precipitation. It will be noted that the evaporation under trees is about one-half of that in open fields. The precipitation is that of the open fields and, for the German stations and years reduced (the ten years, 1879 to 1888), its annual value was 34.3 inches (871 mm.). The evaporation in the fields for the same stations and time was 12.7 inches (322.5 mm.) annually, and that in the woods, 5.4 inches (137 mm.). The corresponding percentages of evaporation were 37 and 16, showing a saving of 21 per cent, of the precipi-

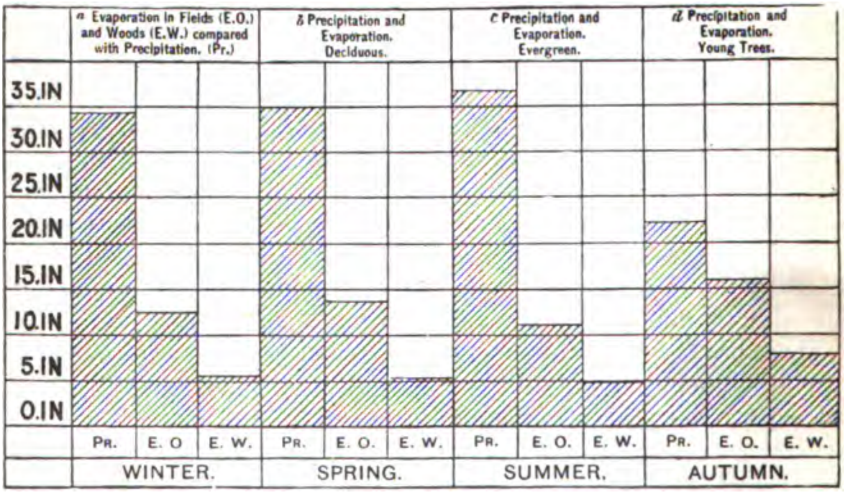


FIG. 49.—Evaporation and precipitation.

tation by the woods. Fig. 50 exhibits the distribution of the evaporation for the year. The upper line represents the progress for the water surface in the open air, the lower that for the same in the woods. The shaded space indicates the saving, in inches, of a sheet of water

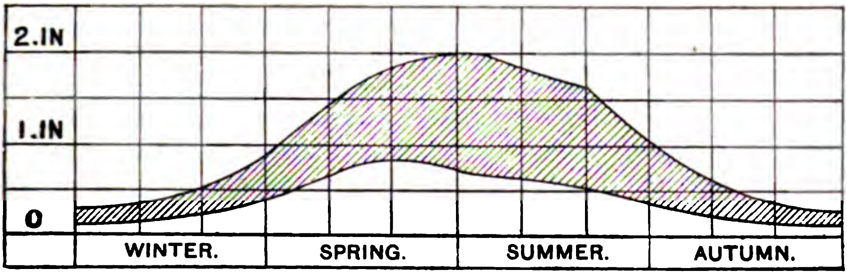


FIG. 50.—Monthly evaporation in the fields (upper curve) and woods (lower curve).

which is affected by the cover of the forest in lessening evaporation. The evaporation and its saving by the woods are both greatest in May and June and they decrease symmetrically on each side of these months. The amount in the winter months is very small, and it is, moreover, somewhat uncertain, as it is difficult to make the observations at that season. The annual evaporation in the woods is 44 per cent of that in the fields. Fig. 51 represents the percentage for the different months of the year. The upper straight line stands for 100 per cent, or the evaporation in the fields during the year, and the curve below represents the percentage in the woods. The shaded space is the percentage of field evaporation which is saved by the forest. This covers a full half of the diagram, with some addition to this from May to November. It is also interesting to compare the evaporation from a water surface with the precipitation from month to month. This is done in Fig. 52.

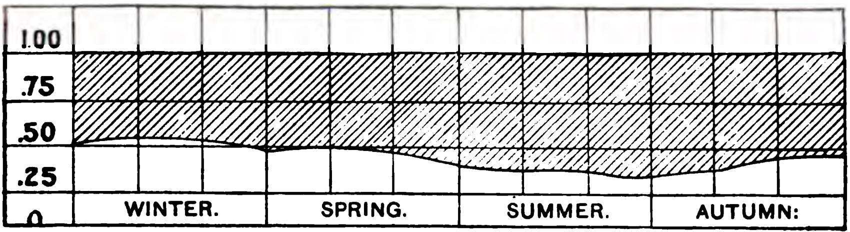


FIG. 51.—Percentage of evaporation in the woods as compared with that in open fields.

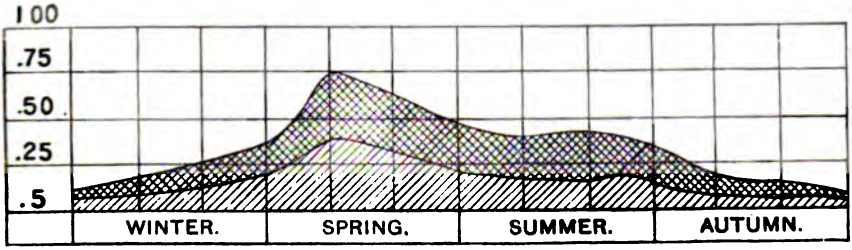


FIG. 52.—Ratio of evaporation from water surface in field (upper curve) and forest (lower curve) to precipitation (top line).

The upper straight line represents precipitation, while the upper curve represents evaporation in the fields, the lower that in the forest. Previous diagrams showed that the amount of evaporation increased rapidly up to May and June; this one shows that the percentage of rain evaporated increases even more rapidly and reaches its maximum in April, a month earlier. From this point it descends more slowly to the winter months, when the minimum is reached. Almost the same course is taken by the evaporation within woods. The hatched spaces below represent the percentage of precipitation evaporated within woods and without, the cross-hatched part that saved by the woods or evaporated in open fields in excess of that evaporated in woods. The saving is greatest at the time when the evaporation could dispose of the largest percentage of precipitation, namely, in spring and summer.

It is interesting to see whether the evaporation phenomena present any difference with different kinds of trees or with trees of different ages. Figs. 49*b* and *c* exhibit the annual quantity of precipitation and evaporation for stations under and outside of deciduous and evergreen trees respectively. It will be noticed that the saving of evaporation under trees is more marked for deciduous trees. The percentage of evaporation in forests to that outside is 41 for deciduous trees and 45 for evergreens. Fig 49*d* gives the same data for young trees. It will be noticed that the percentages are here entirely changed. The evaporation in fields approaches the quantity of precipitation (which is here small), while the evaporation under trees hugs closely that in the open. The evaporation in the open is here 73 per cent of the rainfall while that under trees is 58 per cent, which is 80 per cent of the former.

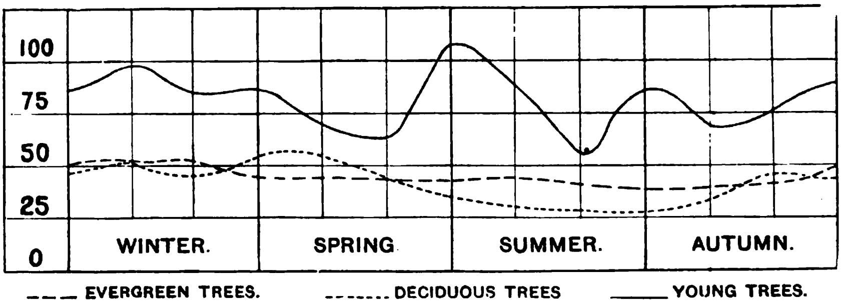


FIG. 53.—Percentage of evaporation in woods to that in the open air.

Fig. 53 gives the percentages of evaporation in woods compared to that outside for the various months. That for deciduous trees (the dotted line) varies more during the months and sums up slightly less for the year. The effect of the leafless condition in early spring is faintly visible.

The unbroken line represents the percentages for young trees. It is very uneven (on account of the series of observations, only seven years), but it runs much higher and occasionally the evaporation under the trees is greater than that outside.

Dr. Ebermayer's series of observations included more elaborate ones on evaporation than those of the German service. In addition to the evaporation from a water surface he also measured that from bare soil outside the forest and within, and that from soil in the forest which was covered by forest litter. The latter observations were made only in the months from April to October. His instruments were first a simple one, somewhat like that of the German service already described, and then the evaporometer of Lamont. The evaporation from earth, either naked or covered with litter, was measured by an apparatus which worked on the principle of the student lamp and kept the earth always saturated. The vessel containing the earth is of zinc. The instruments are protected from the sun, rain, and snow, but the air is given free access to them. The following table gives the percentages which are derived from his results, with some corresponding ones from the German stations to permit comparison. The evaporation from a water surface is the mean for six stations for three years; the other evaporation percentages are for two, with the exception of two months. The precipitation is for one year. The percentages are always made from the averages for corresponding years. The data from the German observations are for ten years.

Evaporation in woods in per cent of evaporation in the open.

	Dr. Ebermayer's results.						German observations.		
	Water surface.		Bare soil.		Soil under forest litter, and within forest.	Rainfall.	Water surface.		Rainfall.
	Open.	Woods.	Open.	Woods.			Open.	Woods.	
April	1	.45	1.15	.64	.27	1.75	1	.51	1.37
May	1	.43	.91	.37	.16	.68	1	.47	1.35
June	1	.36	1.07	.38	.14	1.46	1	.41	1.91
July	1	.35	.89	.34	.12	1.02	1	.38	2.33
August	1	.34	.87	.36	.11	1.00	1	.36	1.98
September	1	.33	.92	.39	.11	.59	1	.35	2.54
October	1	.41	1.26	.44	.18	3.45	1	.37	8.49
May-September	1	.36	.93	.35	.13	.95	1	.39	2.02

This table brings to light several interesting facts. The ratio of evaporation without and within woods is about the same in the two services, giving confidence to the generality of these figures. It appears, however, that the evaporation from a bare soil is about the same as that from a water surface. This is very large and is probably due to the fact that the soil is always kept saturated. The ratio between evaporation from bare soil within woods and without is about the same as that for the water surface.

The most striking feature of the table is the effect of the presence of forest litter on the evaporation from the soil within forests. The character and depth of this litter would make much difference, and it was probably kept as nearly as possible like that lying naturally in undisturbed woods. In this series of observations, even with saturated soil underneath, it permits an evaporation of only 0.13 per cent of a free water surface. About seven-eighths of the evaporation from the forest is cut off by the woods and litter together.

The ratio of evaporation from a water surface to the precipitation for the same months is surprisingly large. According to these observations 5 per cent more than the precipitation during the warm season could be disposed of by evaporation from a water surface. Many surfaces permit a readier evaporation, and if we add to evaporation from a meadow, for instance, the large transpiration from the grass, it would appear that on the average more water must be evaporated than falls during this season, which is very improbable. The German observations give a more probable value, that of one to two. Evaporation is very readily affected by slight causes, and it appears probable that Dr. Ebermayer's instruments, or their exposure, may give occasion to an increase of evaporation as compared with the German stations. The annual rainfall is about the same for the period for which results are published from the two services—34.3 inches (871 mm.) in the one case, 34.5 (876 mm.) in the other. The amount of water returned into the air over a forest is a quantity worth knowing, even though roughly approximated, especially if it can be prepared with that from other forms of vegetation and from bare soil. The forest air is furnished with vapor by the forest through transpiration from the trees, through evaporation from the soil, and through evaporation from the trees. The transpiration has already been estimated at 6.5 inches. This (and other special action of the forest) is practically confined to the warm season, which may be considered as extending from May to September, these months included. The evaporation from a free water surface in the open at the German stations for this time is 8.39 inches (213 mm.). The transpiration is, therefore, 6.5÷8.39=0.77, or 77 per cent of this evaporation.

The evaporation from the soil under forest litter is, according to Ebermeyer, 13 per cent of that of bare soil in the open in the warm season. Dr. Wollny has carried on several series of observations on evaporation through a forest litter, and from these it appears that the litter reduces the evaporation by one-fourth or one-third. This would give three-fourths of 0.39 or two-thirds of 0.39, which are 0.30 or 0.26, numbers considerably larger than Dr. Ebermayer's. As the latter's observations were made on an observational scale while Dr. Wollny's were only on an experimental one, we will take Ebermayer's result of 0.13 as the measure of evaporation in woods.

Only 70 per cent as much rainfall reaches the rain gauge in the woods as falls in the open fields, the rest is caught in the leaves or branches and moistens these and the trunk.

Very little runs down the trunk, as has been shown by the observations at Nancy.[1] This 30 per cent of rainfall must be again evaporated, since the plant takes up little or no water in that way. We have, therefore, to add to the other forest additions to the vapor of the air 0.30× 2.02=0.61 per cent of evaporation from a free water surface in the open air. To this should be added the amount of dew which is evaporated, but this is unknown, and as it is condensed from the adjacent air at night to be added to it again in the daytime, its omission will not make the result less significant. The moisture added to the air is, therefore, roughly, for the warm season:

---

[1] This statement is based on observations made under one tree, the kind and conditions of which are not even stated, and the conclusions have been refuted by the

By transpiration, .77 per cent of the free surface evaporation.
By interior evaporation, .13 per cent of the same.
By evaporation of rainfall, .61 per cent of the same.
Total, 1.51 per cent of the evaporation from a water surface in open fields.

To get the total in terms of the precipitation, this result is to be divided by 2.02, giving 0.75.

As to other forms of vegetation various estimates are given, but Dr. Wollny within a few years has made a series of careful measurements. From them, by reducing, we get—

For mixed crops and fallows 1.44 of evaporation.
For clover, wheat, oats, etc., 1.73 of same.
For sod, 1.92 of same.

These values are conservative, other authors giving generally larger ones. The evaporation from bare soil varies much with the kind of soil and its degree of saturation with water.

As Dr. Ebermayer kept the soil constantly saturated, his results do not represent natural conditions. The evaporations from soil in open fields will be cut down by general lack of sufficient moisture to saturate them. Schubler's value of soil evaporation has, therefore, been used. By it the soil evaporates 0.60 as much water as a water surface sheltered from sun and wind, but otherwise freely exposed to the air. Tabulating the results, we find that the percentages of additions of moisture to the air over different kinds of vegetation are about as follows for the warm season:

Evaporations from various kinds of vegetation.

	Of evaporation from a free water surface.	Of precipitation.
Sod	1.92	.96
Cereals	1.73	.86
Forest	1.51	.75
Mixed, etc	1.44	.72
Bare soil	.60	.30

Austrian measurements of Riegler, published in the Journal of the Forest Experiment Stations in 1879, from which it would appear that the rainfall reaching the soil is increased by from 3.4 to 19.6 per cent through the water running off along the trunks, according to the kind of trees; the first figure referring to spruce, the last to beech. The total loss of water by interception may then be averaged to be 12 per cent of the rainfall instead of 30. See also p. 134 of this bulletin.—B. E. F.

It appears that the forest is of medium activity in this regard. It is usually surpassed by the ordinary forage crops, but surpasses ordinary fallow growths and far surpasses the average bare soil.

Still, the forest exercises a strong conservative effect on the waters within and under it. It saves the most of its ground water from evaporation, and a great deal of the water above the surface. It differs from other forms of surface covering in drawing its water from a greater depth. It therefore does not dry out the surface so much, and it is also less sensible to temporary droughts. Although less effective, on the average, in adding vapor to the air than are many less herbaceous forms of vegetation, it is more steady in its action, and it therefore adds its moisture when it is most needed. During continued dry weather the roots of the grasses dry out the surface soil and exhaust its water. They then cease pouring moisture into the air. At such times the forest may continue its transpiration and at the same time, by its preservative action, its soil is charged with moisture and may continue to feed the springs tributary to it.

FORESTS AND HUMIDITY.

The psychrometer observations, within and without forests, permit a study of absolute and relative humidity. The comparative results for the absolute humidity are given in the accompanying table in the form of the values of $W-O$. The plus sign indicates a great amount of vapor in the air of the forest; a minus sign the reverse. The units are hundredths of a millimeter of mercury as it would be shown in a barometer. The first part of the table is derived from the German observations. To it are added the values calculated from the observations in forest and glade ($W-G$), and in forest and plain ($W-P$), from the Swedish service.

	Winter.	Spring.	Summer.	Autumn.	Year.
At base of tree:					
General average	+ 2	− 3	− 5	+ 8	+ 0
Deciduous	+ 2	− 7	−11	+ 6	+ 2
Evergreens	+ 2	- 3	− 5	+ 8	0
Young	+ 9	+37	+26	+39	+37
At tree crown:					
General average	+ 1	+ 1	+10	+ 1	+ 3
Deciduous	0	- 1	−10	+ 1	− 2
Evergreens	+ 1	+ 2	+10	+ 4	+ 4
Swedish observations at base of tree:					
$W-G$	+ 7	+ 7	+15	+13	+10
$W-P$	+10	+13	+ 7	+ 7	+ 9

These numbers are very small, so small that, notwithstanding the absolute humidity is itself of small amount, they are usually less than 1 per cent of it. This is true of the German observations, except for the young trees. Here the value of $W-O$ is always positive and reaches up to 4 or 5 per cent of the total absolute humidity. This may be due to the surroundings of this station, which is on the Lüneburger heath, an immense tract of moorland occupying the eastern part of Hanover. There is no distinct difference between tree crown and base nor between glade and plain. In the individual stations the mean is frequently larger than the average of all, and is sometimes consistently positive, in other cases regularly negative. It appears, as might be expected, that there is no general difference between the absolute humidity in woods and outside, and the differences in individual stations may be due more to the surroundings of the station in open fields than to the forest. The lack of a characteristic absolute humidity in forests can be completely explained by the fact, already shown, that the forest is not an especially active producer of the vapor of water. Its position in this respect is intermediate; and even if it did produce a peculiarly large or a specially small amount of vapor it would not be apt to show a peculiar absolute humidity because of the rapid connection and mixture of gases. A gas spreads in all directions and with great rapidity usually from the point where it is produced. An observation by M. Becquerel illustrates the fact that a source of vapor need not give the air about it a higher absolute humidity. He compared, on a summer's day, the psychrometer readings in the air at 5 feet, just over a tree, just over garden vegetables, and just over a stream, and found the absolute humidities to be practically identical. However much these surfaces may have differed in the production of vapor, the rapid connection and mixture prevented this difference from being appreciable as absolute humidity of the air.

While the absolute humidity depends only on the amount of the vapor of water in the air, the relative humidity depends on this and on the temperature also. As a difference in temperature between woods and open fields has already been shown, there must be a difference in relative humidity, and as the temperature of the woods is lower the relative humidity must be higher, or the value of *W—O* must be positive. The following table shows that this is the case:

	Winter.	Spring.	Summer.	Autumn.	Year.
At the base:					
General average	+2	+2	+6	+5	+4
Deciduous	+2	+1	+7	+5	+4
Evergreens	+2	+4	+5	+4	+4
In tree crown:					
General average	+1	+2	+3	+2	+2
Deciduous	+1	+1	+2	+1	+1
Evergreens	+1	+2	+4	+3	+2
Swedish observations:					
W—G	+1	+4	+4	+2	+3
W—P	+2	+5	+4	+2	+3

There is no great difference in the different cases. The surplus in the tree crown is a little smaller because the temperature is higher there.

M. Fautrat has carried on some observations of humidity above trees, but his results, as published in the *Comptes Rendus*, are fragmentary. They are given in the accompanying table as they were published. The results in absolute humidity were not published. The observations over trees are compared with those at the same height over fields and about a thousand feet distant. The psychrometer was several feet above the trees in the case of the deciduous trees, but close to the top of the evergreens.

	Forest of Halatte deciduous trees.				Forest of Ermenonville evergreen trees.			
	No. of years.	W.	O.	W—O.	No. of years.	W.	O.	W—O.
January	0	......	......	......	0	......	......	......
February	1	87	84	+3	1	80	71	+ 9
March	2	71	69	+2	1	74	63	+11
April	2	64	62	+2	2	55	48	+ 7
May	2	64	61	+3	2	57	48	+ 9
June	2	60	57	+3	3	61	55	+ 6
July	2	60	57	+3	3	57	48	+ 9
August	1	56	54	+2	2	57	50	+ 7
September	1	77	75	+2	2	65	58	+ 7
October	1	80	77	+3	2	79	71	+ 8
November	1	82	79	−3	2	79	72	+ 7
December	1	83	81	+2	2	65	60	+ 5

The surplus of relative humidity over deciduous trees is not great, but that just over the foliage of evergreens is so large as to be significant. The published results do not admit of a ready computation of the absolute humidity, but the surplus of the relative is great enough to suggest a surplus of the absolute, large enough to be easily measured. The special, elaborate, and refined observations at Ried, in Austria, show slightly greater variations in absolute humidity than previous ones, and though they are nearly evanescent, some uniformity can be traced in them. As they were taken at irregular intervals they are not suitable for a general tabulation and their number forbids their being quoted at length. The conclusions reached by the discussion of them and given by Dr. Lorenz Liburnau are as follows:

The absolute humidity decreases in the forest from the soil upward. The rate of decrease is usually the greatest under the trees and the least at the level of the foliage. The rate above the trees is intermediate between the other two. This rate is least in the late hours of the night, when it may be zero. It increases with the increase of the temperature of the air, becoming greatest in the midday hours, when, under exceptionally favorable circumstances, it may make a difference of 10 per cent, or even more. Occasionally, in high winds, the absolute humidity is greater over the trees. Over the field station the daily progress of the absolute humidity was about the same as in the forest, but the maximum difference was only about half as great. The absolute humidity in and above the forest is greater than that over the open fields, and there is some trace of an increase of this difference to the time of maximum.

The relative humidity decreases upward in forests, but there is an occasional reversal of this at night. Over the open fields it decreases upward with wet soil, but increases with dry. It is almost invariably greater about the forest, above as well as inside, over the field station, and it is higher above the forest than it is at 5 or 6 feet above the open field. The small significance of the vapor poured into the air by forests in raising the absolute humidity suggests the question of the relations of the forest to other constituents of the air. The forest takes up large quantities of carbonic acid, retaining the carbon and rejecting the oxygen. Does it sensibly change the relative quantity of either constituent so that the composition of the air is slightly different in the woods? Repeated observation shows that each constituent is curiously uniform in quantity in the free air. It has been thought the carbonic acid is quite variable, but the introduction of better methods of observation shows that, except in confined places where the gas is produced, the variations are very small.

A study of the numbers involved will show that the carbonic-acid gas taken up by a forest is a vanishing quantity compared with that which passes the forest in the same time with the moving air. Grandeau gives the annual product of carbon by a forest of beeches, spruces, or pines as about 2,700 pounds per acre. This corresponds to 9,900 pounds of carbonic-acid gas, or 69,300 cubic feet. Now, if the average motion of the air is 5 miles per hour (a light breeze, a low estimate), and the layer of air from which the gas is taken be estimated at 100 feet thick, there would pass over an acre 550,000,000 cubic feet in one hour. This air must contain about three parts in ten thousand of carbonic gas, and the total amount of the latter per hour is 165,000 cubic feet. But this is 2⅜, or more than twice as much as that taken up by the trees in the entire season, so that the air could provide in thirty minutes for the wants of the trees for the entire season. If this season is taken at 5 months, or 150 days, the amount of air passing is $55 \times 10^7 \times 24 \times 150 = 198 \times 10^{10}$ cubic feet, and the amount of carbonic-acid gas is 594×10^6. The ratio of carbonic acid used to that furnished is only $\frac{69300}{594000000}$, or one part in 8,600.

The additions of oxygen to the air would form a still smaller percentage of the oxygen already present, for this gas makes up a quarter of the air instead of a thirtieth of 1 per cent.

The case is somewhat different with ozone, as it is formed in certain definite localities and its eagerness for combination is such that it can not pass far from its source before it will disappear. The resins of coniferous woods should be an abundant source of ozone, and although the decaying matter in and about woods provides abundant occasion for its disappearance before passing off into the outside air, still the amount of ozone in such woods should be sensibly greater than outside. Observation has not shown this unequivocally, but that may be due to the numerous imperfections of the method employed.

RAINFALL IN, ABOVE, AND NEAR FORESTS.

The first result from the parallel system of forest observations with regard to rainfall is the determination of the quantity of rain under trees as compared with that outside. Aside from any possible difference of rainfall over forests and outside, the tree and its foliage serve as a cover for the space underneath. The result is that the rain gauges under the trees fail to get as much precipitation as those which are in the ópen fields. Generally the rain gauges are alike in the two stations. Much difference is caused by the position in which the forest rain gauge is placed, whether under a crown of dense foliage or near its edge, or under the lighter foliage of smaller or scattered trees. Very little information is given on this point. The rain actually caught annually under trees in the German service varies from 89 per cent of that in the open (at Carlsberg) to 52 per cent (at St. Johann). The average is 75 per cent, or three-quarters; and ten of the sixteen stations do not vary 5 per cent either way from this mean. A twelve-years series of observations gives, for the three Swiss stations, 90, 84, and 77 per cent, giving a mean of 84 per cent, considerably larger than that given by the German stations.

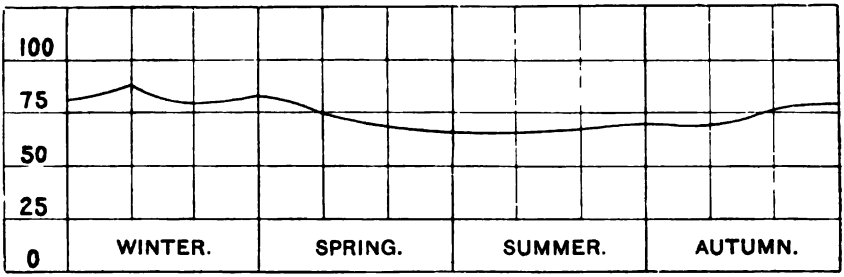


FIG. 54.—Percentage of precipitation received under trees (all kinds)—German observations.

The station at Bellefontaine, near Nancy, also gives 84 per cent as the mean of eleven years of observation.

The proportion of the precipitation which passes through the foliage varies slightly with the season. Fig. 54 shows the relative amounts (percentages of outside precipitation) for the individual months. The percentage withheld is somewhat greater in the warmer season, though the difference is not great. Fig. 55 distinguishes between the evergreen and deciduous trees. The values for the evergreens are represented by the broken line. They appear very even, with only a slight tendency downward in the warm season. The dotted line is the curve of the percentages for deciduous trees. It is less even than the other. The dip downward is decidedly more marked, but it is not great. It would seem that the advent of the foliage would have a much greater effect than that represented by the slight turn downward of the curve from April to June. The drop for deciduous trees during these months is from a percentage of 77 to that of 66, then to 65, making the foliage catch but 12 per cent of the precipitation, while the bare limbs and twigs in March caught 14 per cent, and in April apparently 23 per cent. The evergreen trees permit 73 per cent of the rainfall to pass through their foliage in April and identically the same in June. Admitting (though there are some reasons for doubt) that the rainfall is actually the same over a wood and a place outside but near, this small action of the foliage as compared with the branches and twigs requires explanation, and, whatever the explanation may be, it must apply only to deciduous trees, as evergreens show no difference in these months. No satisfactory explanation occurs to me. The catch in winter is largely influenced by the form of precipitation, the snow being caught temporarily and let fall later into the gauges below, but this would not affect the fall from April on.

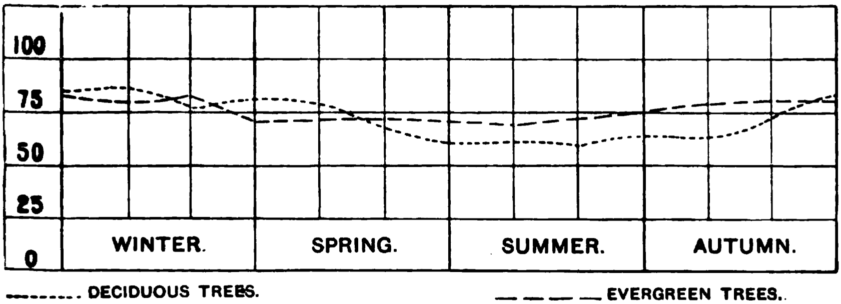


FIG. 55.—Percentage of precipitation, received under trees (different kinds).

The foliage catches more of the rainfall during the warm season, even in the case of deciduous trees. The percentages for the German stations are as follows, the warm season being taken from May to September, five months:

	Entire year.	Warm season.
General average	75	70
Average for deciduous trees	74	65
Average for evergreens	77	74

It seems that the deciduous trees withhold more of the precipitation (3 per cent) through the entire year than do the evergreens, and that this percentage additional becomes 9 in the leafy season.

Less than two-thirds of the rainfall in open fields, during this season, succeeds in reaching the gauge under deciduous trees; more than three-quarters reaches it under evergreens. This difference may be easily due to the character of the foliage in the two cases.

As an average from sixteen stations, and about 150 years of observation, it is found that, in the warm season, 30 per cent of the rainfall in the open fails to reach the gauges under the trees. Taking all seasons together this deficit under trees is 25 per cent. The disposal of this water is easy to explain. It does not include the water that drips from trees, for this is fairly accounted for by the gauges. It is the water which moistens the tree and its various parts, and also that which flows down the trunk. The latter part reaches the soil and is measurable; the former is evaporated again without reaching the soil. At Nancy arrangements were made for including in the catch of the gauge the part which flows down the trunk. At two stations large gauges were put in; they were of the same size as the tree crown and they embraced the trunk, a collar about which directed the water into the receiver of the gauge. The percentage of catch in the woods was here 92, the largest in stations provided with ordinary gauges. The latter were used at the Bellefontaine station, which was not very distant, and the catch was here 84 per cent. This is larger than for most other reported returns, but the difference between this value and that for Cinq-Franchées may perhaps be taken as an approximation to the quantity of rainfall which flows down the tree trunk. This would be 8 per cent. These are means from eleven years of observation. Fig. 56 gives the distribution of the percentages through the year. The upper curve is for Cinq-Franchées with its large rain gauge; the lower curve is for Bellefontaine with ordinary gauges. They both show something of the dip for the warm season. At Cinq-Franchées the precipitation under trees for one month (February) is slightly larger than that in open fields.

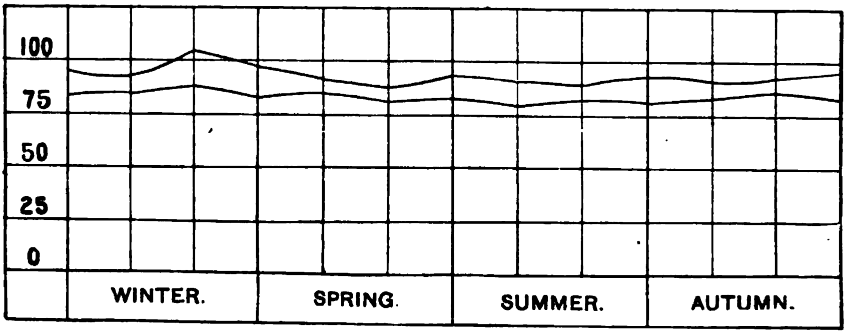


FIG. 56.—Precipitation through trees at Cinq-Franchées and Bellefontaine.

M. Fautrat's observations include those on precipitation above forests. The rain gauge over the forest was compared with one at the same height and a thousand feet away, over fields. The two pairs of stations were in the forests of Halatte and Ermenonville, and have been already described. The accessible data were, for Halatte, the monthly values for February to July, 1874, and August, 1876, to July, 1877; for Ermenonville, the monthly values from 1875 to July, 1877. These have been changed into inches and condensed into the accompanying table:

	Halatte, deciduous trees.			Ermenonville, evergreens.		
	W	*O*	*W—O*	*W*	*O*	*W—O*
Winter	7.44	7.35	+0.09	6.11	5.41	+0.70
Spring	6.90	6.54	+0.36	7.47	6.74	+0.73
Summer	7.11	6.69	+0.42	9.25	8.29	+0.96
Autumn	8.88	7.32	+1.56	7.24	7.20	+0.04
Year	30.33	27.90	+2.43	30.07	27.64	+2.43

These results are of so great interest that it is unfortunate that the published series of observations is so short. Rainfall observations, to give satisfactory results, must be derived from a long series of observations. M. Fautrat's observations are very consistent among themselves, however, and the uniformity of signs of *W—O* and the distribution of the values through the season show that they are not due to accidental limits of heavy rains so arranged as to include one station and exclude the other. According to these observations, the simple precipitation over woods is 9 per cent more than that over open fields in both cases. The amount which reached the ground under the woods was 90 per cent of that over the fields for one year in the case of the deciduous trees, and this gives the large average percentage of 39 for that which was caught by the foliage. For the evergreen trees and the whole series of observations the amount which reached the ground under trees was only 56 per cent of that in the open, giving here 53 per cent as the catch of the trees. The arrangements of rain gauges by M. Fautrat did not permit the measure of the amount flowing down the trunks. Using the per cent obtained at Cinq-Franchées as the measure of this, we have the following curious and interesting relations between the precipitation over woods, in woods, and outside. The data are percentages of the rain of all outside, in this case at the height of the upper gauge, as that at the lower gauge is not given.

	Fall over woods.	Reached gauge under woods.	Reached ground under woods.	Held by the foliage.
Deciduous trees	1.09	0.70	0.78	0.31
Evergreen trees	1.09	0.56	0.64	0.45
Average of two	1.09	0.63	0.71	0.38

While Fautrat's observations show that there was a higher rainfall over trees in the department of Oise than over comparative stations in the open fields, they do not show that that occurs in Germany or elsewhere, but gives enough of a presumption to that effect to make it worth while to examine the subject more fully. It frequently happens at the German stations that the heaviest rainfalls for the month (which are always noted) are greater under trees than at the field station, but as this could easily be due to heavy local rains, it is not especially significant. It is otherwise with the monthly rainfalls. If the monthly amount under trees is greater than that outside, there is a fair presumption that the rainfall over the trees is persistently heavier, and where this is found for several months, and in the warm season when the precipitation is rain and can not be very long sustained in the foliage, the presumption becomes very much stronger. There were a good many cases in the two hundred years of observation at the German stations when the monthly catch under woods was greater than in the open fields. I will take a few of the most interesting, for the warm season:

Carlsberg, May, 1881 (1.24), and September (1.11); also September, 1885 (1.20), June, 1887 (1.20), and May, 1888 (1.14); Schoo, May to September, 1886 (1.05, 1.00, 1.04, 1.40, 1.40).

These are both stations among evergreens, and the summer reduction of catch under trees for this season, for the German stations, is .26 per cent. If this is added to the above they become—

For Carlsberg	1.50, 1.37, 1.46, 1.46, 1.40
For Schoo	1.31, 1.26, 1.30, 1.66, 1.66

and it appears that the monthly fall in the woods may be from a fourth to two-thirds more than in adjacent fields. If instead of the .26 per cent of the German service, the .45 per cent found by Fautrat, by actual measurement, as the difference in rainfall above and below evergreens, be added, these values become .19 per cent greater, and the rainfall observations at the forest stations generally become larger than those in open fields.

But Fautrat's .31 per cent for deciduous trees and .45 per cent for evergreens are the results of brief series of observations at only two stations and can not be extended to the results of observations at other stations without uncertainty.

They afford, however, some grounds for the presumption that rainfall is heavier over woods, and it is not hard to find reasons why it should be. But it is most satisfactory to wait until the fact has been proven beyond a doubt, and in the lack of sufficient observations on this point lies the chief and most important gap in forest meteorological work. For the completion of the theory of the action of forests on climate exact observations are needed above trees at many stations and for long series of years, and the most important data to be obtained are those relating to precipitation. The rainfall caught under trees is of minor importance—far subordinate to the amount caught above trees.

PRECIPITATION OVER WOODED AND TREELESS DISTRICTS.

This branch of the forest meteorological problem is the most important of all, has been most discussed, and the discussion has resulted in all shades of opinion, from those absurdly favorable to trees to those utterly adverse. Direct comparison of observation is here not possible, or at least comparable observations have not been carried on, and, as in the case of temperatures over wooded and treeless districts, there is always occasion for doubt whether the differences found at the selected different stations are not due to other things than the presence or absence of forests. The difficulty is, in fact, greater here than in the case of temperatures, because the rainfall is especially sensitive to all sorts of conditions and surroundings, and is also apparently very capricious (changing from month to month or year to year by large amounts and without any discoverable cause). In addition to all this, when a difference of rainfall corresponding to a difference of forest conditions has been found, there is still occasion for doubt as to which is cause and which effect. There is every reason to believe that with increased rainfall, other things being favorable, there will be an increased growth of trees.

The facts at hand do not prove, with entire conviction, that forests increase the rainfall. The historical method is lacking generally in the character of the data for the beginning of the comparison. Besides, where a change of rainfall is actually shown to be coincident with a change in the forest growth it is not entirely certain that the former is due to the latter; it may be due to what are called secular changes of the rainfall, the reasons for which lie beyond our knowledge. The geographical method is not entirely satisfactory, for the reasons already mentioned. The entirely convincing method depends on observations above forests and with systems of radial stations as proposed by Dr. Lorenz-Liburnau, and from these there is not yet a sufficient amount of published results.

It will be of interest, however, to see what is the character of the geographical method so far as it relies on purely meteorological facts.

In 1866–1868 M. Becquerel took a series of observations of rainfall at five stations, at Montargis and Chatillon-sur-Loing, and their vicinity. They are in the department of Loiret, 50 to 75 miles (80–121 kilom.) south of Paris, and contained within a range of 25 or 30 miles (40–48 kilom.) of a country with fields and woods interspersed. His observations gave results as follows:

Station.	Condition.	For 1866.	For 1866–1868.	
		Inches.	*Inches.*	*Mm.*
La Jacqueminière	Wooded	33.30	27.10	688
La Salvionnière	Wooded	32.51	27.09	688
Le Charme	Wooded	31.09	(27.08)	687
Chatillon	Open	24.38	26.25	666
Montargis	Open	24.16	26.94	684

At the end of the first year's observations M. Becquerel calls attention to the larger amount of rainfall at the more wooded stations; at the end of three years, however, he practically recalls this mild suggestion. The observations were taken for two years only at Le Charme and were corrected to make a mean corresponding to that for the three years at the other stations. M. Becquerel also examined the relations of rainfalls to forests in Denmark, but the results were somewhat ambiguous.

The observations made near Nancy were arranged in such a way that some conclusions could be drawn as to the relative rainfall among forests and in open country.

Cinq-Franchées was in the midst of the large wooded plateau called the forest of La Haye, composed of deciduous trees about forty years old.

The field station was in an open space of 10 or more acres, in which was the house of the forester. It was 5 miles southwest of Nancy. Bellefontaine was on the edge of the forest, about 4 miles northwest of Nancy. The field station was uncultivated land, devoted to nurseries. It was in the bottom of a valley running northwest and southeast. Six miles northeast of Nancy was the station of Amance, near the summit of a hill, and surrounded by cultivated lands, not entirely treeless, but devoid of forests. Observations were begun later at the agricultural station near Nancy. It was in the open fields about 11 miles from the forest of La Haye. There are only seven years of observations from this station, but eleven from the others. The mean annual precipitation at these stations is given in the accompanying table:

Station.	Condition.	Altitude.	Mean of seven years.	Mean of eleven years.
		Feet.	*Inches.*	*Inches.*
Cinq-Franchées	Forest	1,247	32.5	31.5
Bellefontaine	Forest	787	31.8	30.7
Amance	Open	1,247	25.5	25.7
Nancy	Open	712	30.4	....

The stations at Cinq-Franchées and Amance are as comparable as stations can be made, and the forest precipitation proves to be about 7 inches greater than that of the open fields. Bellfontaine, on the edge of the forest, has an appreciably greater precipitation than Nancy. These stations were all under one direction, and their results may be considered as significant, especially as to the first and third, which are at the same elevation. The position of the second is unfortunately of such a character that its rainfall might be very sensibly affected.

The rainfall at parallel pairs of field stations has been determined by a series of careful observations. These stations are always near forests, and it will be of interest to compare their results with those given for extensive regions near them but without forests. Such a comparison is made in Dr. Lorey's handbook of forestry; in reproducing it the units of measurement are changed to feet and inches. The stations are arranged in the order of their elevation above the sea. The averages for the larger regions are those published by Dove in 1871.

Field station.			Compared with average over open regions.		
Name.	Elevation.	Mean annual precipitation.	Name.	Mean annual precipitation.	Surplus over woods.
	Feet.	*Inches.*		*Inches.*	*Inches.*
Schoo	10	28.4	North Sea coast	27.5	+ 0.5
Eberswalde	77	21.9	Brandenburg	21.8	+ 0.1
Fritzen	98	25.6	East Prussia	24.1	+ 1.5
Hadersleben	112	30.1	Baltic coast	26.0	+ 4.1
Lintzel	312	23.3	Hanover	26.9	− 3.6
Kurwien	407	24.5	East Prussia	24.1	+ 0.4
Marienthal	469	22.5	Thuringen and Saxon provinces	23.2	− 0.7
Hagenau	500	31.6	Alsace-Lorraine	30.4	+ 1.2
Neumath	1,159	32.3	do	30.4	+ 1.9
Friedrichsrode	1,158	26.5	Thüringen and Saxon provinces	23.2	+ 3.3
Lahnhof	1,975	44.2	Westphalia	30.7	+14.5
Hollerath	2,005	38.3	Rhine country	25.6	+12.7
Schneidefeld	2,230	50.2	Thüringen and Saxon provinces	23.2	+27.0
Carlsberg	2,400	38.9	Silisian Mountains	27.2	+11.5
Sonnenberg	2,549	55.5	Harz	36.4	+19.1
Melkerei	3,071	69.9	Alsace-Lorraine	30.4	+39.5

It seems from this that, where the results at the stations near forests are compared with the general results in the section of country in which the station is situated, the forest station usually shows more rainfall. Lintzel is exceptional, because near young trees on an exposed moor.*

---

* In regard to this station Dr. Müttrich has lately published an interesting account which should correct the above result, and would go far to show a noticeable influence of the growing forest cover upon rainfall.

This station, situated in the Luneburg heath, was begun to be planted to forest in 1877, at the rate at first of 1,000 to 1,500 acres per year, afterwards more slowly, and by this time over 8,000 acres have been planted to forest in that locality. Around the meteorological station a young forest of 10 to 12 years old, of pine and oak, has grown up. The station is placed in an open field of about 75 acres extent, surrounded by the forest growth. The change of conditions immediately around the station Lintzel, making Lintzel central for an area of about 25 square miles, is represented as follows:

Before reforestation:	After reforestation:
12 per cent field, meadow, etc.	10 per cent field, meadow, and water.
85 per cent heath.	10 per cent heath, roads, and openings.
3 per cent old forest.	80 per cent of forest.

There are now regular meteorological observations for nine years on hand.

The rainfall observations are compared with those from stations outside of the forest conditions, but near enough to Lintzel to be available for comparison in the

There are, however, considerable variations in the elevations of the stations employed to get the average values given.

---

following table; the values having in both cases been equalized to eliminate irregularities by calculating the means of each three to four years by the formula

$$\frac{2a+b}{3},\ \frac{a+2b+c}{4},\ \frac{b+2c+d}{4},\ \text{etc.}$$

TABLE 1.—*Equalized values of precipitation, in millimeters.*

Year.	Lintzel.	Bremen.	Lintzel.	Hamburg.	Lintzel.	Oslebs-hausen.	Lune-burg.	Garde-legen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1882	514.7	797.6	514.7	643.7	514.7	673.9	561.0	534.7
1883	550.5	798.8	550.5	650.9	550.5	675.6	575.1	545.0
1884	639.3	821.2	639.3	681.5	639.3	676.3	619.0	599.3
1885	620.3	756.2	620.3	650.2	620.3	579.3	588.7	567.9
1886	533.3	636.0	533.3	570.9	533.3	496.1	512.4	467.1
1887	546.3	568.0	546.3	580.1	546.3	521.2	530.2	454.4
1888	650.0	608.5	650.0	706.1	606.3	578.2	625.2	504.9
1889	705.0	665.9	736.2	781.4	....	....	....	....
1890	668.0	657.3	....	....	....	....	....	....

From this table the percentage of rainfall in Lintzel, as related to the rainfall of each of the other stations, is calculated as follows:

TABLE 2.—*Rainfall at Lintzel calculated as percentage of rainfall at certain places.*

Year.	Bremen.	Ham-burg.	Oslebs-hausen.	Lune-burg.	Garde-legen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1882	64.5	80.0	76.4	91.7	96.3
1883	68.7	84.6	81.5	95.7	101.0
1884	77.8	93.8	94.5	103.3	106.7
1885	82.0	95.4	107.1	105.4	109.2
1886	83.9	93.4	107.5	104.1	114.2
1887	96.2	94.2	104.8	103.0	120.2
1888	106.8	92.1	104.9	93.8	120.1
1889	105.9	94.2	....	....	....
1890	101.6	....	....	....	....

The author concludes that if the increasing reforestation at Lintzel had no influence on the amount of rainfall, the figures for Lintzel should have been nearly in constant proportion to those for the other stations, while from the percentage table it appears that with reference to neighboring stations the precipitation at Lintzel has increased with the increasing forest growth. The differences in the last years are not so apparent, because the values could not be properly equalized. It is, however, undoubtedly proved that at the beginning of observations the rainfall at Lintzel was less than at any of the neighboring stations, and that subsequently it increased from year to year until it was in excess of the other stations, except at Hamburg.

Comparing the rainfall at Lintzel with that of the other stations, and calculating it as percentage of the mean rainfall of the latter, the following series is obtained:

	Per cent.
1882	81.8
1883	86.3
1884	95.2
1885	99.8
1886	100.6
1887	103.7
1888	103.9

This constant increase, going hand in hand with the increase of forest cover in extent and height, leaves hardly any doubt as to the close relation of the two conditions.—B. E. F.

To eliminate this, compare the stations mentioned with other German stations of about the same elevation. For this purpose the rainfalls at 192 stations given by Dr. van Bebber were used, and these and the previous ones were combined for each hundred meters.

Elevations.	Meters 1–100.	100–200.	300–400.	600–700.	100–800.	100–1000.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Average from forest field station	25.8	26.2	29.4	42.9	55.5	69.9
Average from Van Bebber	25.5	22.9	27.4	36.0	38.6	38.0
Surplus for forests	+ 0.3	+ 3.3	+ 2.0	+ 6.9	+16.9	+31.9
Percentage of surplus	1.0	14.0	7.0	19.0	44.0	84.0

This comparison throws some light not only on the amount of surplus over woods, but on the distribution of it. It increases rapidly with the elevation. For 328 feet (99.9 m.) or under, it is but 1 per cent; from this to 1,300 feet (396 m.) it is 7 to 14 per cent; between 1,950 (594 m.) and 2,270 feet (692 m.) it is 19 per cent; between 2,270 (692 m.) and 2,628 feet (801 m.) it is 44 per cent; and above the last the surplus appears to be 84 per cent, or the precipitation over forests is nearly doubled.

It is easy to show that, in general, heavily wooded districts have a high rainfall, as compared to similar districts without forests. This is notably true in India, as shown by Dr. Brandis and others. It is enough to say that the heaviest known rainfall occurs in one of the densest and most extensive known forests, that of the middle and lower Brahmaputra. But in all these cases it is more probable that the forest exists because of the rainfall, rather than *vice versa*. A case which is more favorable to the influence of forests on rainfall is given by Dr. Woeikoff, depending on the rainfall distribution on Java and Celebes. Java has extended and dense forests in the south and in the southwestern interior; while the north coast has been largely deforested. The station Tjilatjap on the south coast is at a distance from mountains. Its annual rainfall is 182.3 inches (4,630 mm.). That for three stations on the north coast (Batavia, Tegal, and Samarang) is 78.4 inches (1,991 mm.) or 43 per cent only. In this region the north side of the islands is the weather side for the northwest monsoons and should have, at least from December to March, more rain than the south side, because this wind descends to reach the latter. As a matter of fact there falls in these months—

At Tjilatjap	45.7 inches	(1,161 mm.)
At the north coast stations	43.3 inches	(1,100 mm.)

or almost as much on the lee side as on the windward, while there should be very much less on the latter.

Celebes, where there is no such deforesting, gives the normal annual values:

Celebes:
  Northern peninsula—windward, 110.6 inches (2,809 mm.); lee, 55.1 inches (1,399 mm.).
  Southwestern peninsula—windward, 136.2 inches (3,458 mm.); lee, 100.0 inches (2,540 mm.).
West Central Java:
  Windward, 78.4 inches (1,991 mm.); lee, 182.3 inches (4,630 mm.).

It appears that in Celebes the windward side has a notably higher rainfall than the lee side, while in Java it is reversed. Is this not due to the relative lack of forest growth on the north side of Java? Where forest growth exists the rainfall is higher, even there. For instance, at Lormadjang, in a densely wooded level area, the annual rainfall is 73.7 inches (1,872 mm.), while at the two nearest stations on the same side it is only 46.9 inches (1,191 mm.).

The literature of the historical treatment of this problem is very great, and the most extreme and absurd opinions can be found registered in it. It usually suffers under the objection, first of imperfect data at the beginning, and always under that of uncertainty as to the cause of any variation of rainfall which may be found.

The argument founded on changes in regions mentioned by ancient writers deserves consideration only to point out its extreme unreliability. The condition of the countries in question at the beginning of the comparison is based on incidental references in the classics which are not only incomplete, but which are usually in ambiguous terms. The classical terms for forest have an extensive range of meaning, as will be seen by reference to any classical dictionary, greater than that of our word forest, which is used in law English to designate areas which now have no woods, and in some cases there is no evidence that they ever had any.

Much more trustworthy are the more modern cases which depend on meteorological observations; but in these the earlier observations are not so trustworthy as to give assurance that any differences found are not the result of imperfect observations. The writer endeavored, some years ago, to show that along the parallels of latitude 40° and 42° in the Mississippi Valley the lines of higher rainfall were moving slowly westward with the advance of settlements, but it was abundantly shown that the sparsely scattered earlier observations were quite untrustworthy.

There is one further case, which is quoted by Dr. Brandis, for India. In the part of the central provinces between the Nerbudda River and Nagpur and Rajpur, embracing a part of the Satpura range of mountains, much attention has been paid for several years to the care of the forests, and specially to protection against forest fires. In consequence a large territory, with scattered tree growth or entirely treeless, has been covered with a dense growth of young trees. Over this region the rainfall has been as follows, at the stations named:

	1875 and before.		1876 to 1885.	Per cent of increase.
	Years.	Mean annual.		
		Inches.	*Inches.*	
Badnur	1867–1875	39.83	47.83	20
Chindwara	1865–1870	41.43	48.48	17
Seoni	1865–1875	52.07	54.76	5
Mandla	1867–1875	53.58	56.32	5
Burha	1867–1875	64.51	71.65	11
Bilaspur	1865–1875	41.85	54.81	21
Rajpur	1866–1875	51.59	54.41	5
Annual average		49.27	55.47	13

From the 37-year series of observations at Nagpur, and the 40-year series at Jubbulpore, on the north side of the Satpuras, it appears that the probable error of a 10-year series of observations is 5 per cent. Further, it appears from the combination of rainfall observations in India that in 1876–1885 the rainfall was 0.66 inch (17 mm.) greater than in 1866–1875.

If one half of the above difference be attributed to error and to a general increase of rainfall, there yet remains an appreciable addition which might be attributed to the growing forest. At least it may be taken as an indication which, combined with the results of observations above trees, makes a good presumption that a forest does actually increase the rainfall by an appreciable percentage. It should be noted that the forest fires practically ceased before 1865, and that at that date the forest growth had been fairly started over small surfaces. By 1875 it had extended over a surface of about 1,000 square miles.*

---

*NOTE.—It seems appropriate in this connection to quote the following extract from Mr. Fernow's annual report for 1888:

"Blandford, who has recorded these observations in the above manner, adds that these results, of themselves, are not proof absolute for the influence of forest preservation, since possibly the earlier observations were less reliable than the later, but that these observations may be considered as addenda to the accumulating signs of the existence of such influence on rainfall.

"But even this method, which would class with my retail methods, although seemingly simple, before it can be admitted as conclusive, must, as the writer says, be guarded by those special precautions which are demanded by strict scientific inquiry.

"The above figures were hailed with satisfaction by those who are bound to prove by statistics the forest influence on rainfall.

"Unfortunately, as this report goes to press, their value is entirely vitiated by the following statements made in the Indian Forester, January, 1889, which again admonishes us to be careful in placing too much weight on statistics.

"Mr. Blandford, in order to assure himself of the value of the rainfall returns he employed in the discussion of the Central Provinces, wrote to the chief commissioner on the subject, to which the reply was received that 'the chief commissioner fears that these records of rainfall previous to 1883 can not be accepted as altogether reliable.' The commissioner explains the reasons why the records appear unreliable, and

The balance of waters in forest regions can not be made up until there is greater certainty as to the precipitation over forests.

It has already been shown that the forest preserves a considerable proportion of the waters which reach its soil. This is due, for the most part, to its lessened evaporation, and this alone would account for the moisture of forest soil, for the preservation of bodies of water, and of perennial springs in regions of dense forest. If the forest also condenses more moisture from the air, then the same effects would follow in regions more lightly clothed with woods.

FORESTS, WIND, AND STORMS.

There remain a few points of more or less interest, which have received considerable discussion, but have not been the object of systematic observation. Among these is the windbreak effect of the forests. Like any other elevation above the surface, the forest protects from the wind objects which are in its lee, and, over a very much smaller area, those which are on its windward side. The outlines of the protected area are defined by the outlines of a snowbank before and behind a fence. A section is given in the accompanying figure, where *A B* is the fence, *W* the snow to the windward of it, *L* that to leeward. The windward protection is so small as not to deserve discussion in this connection. As to the leeward protection, the chief point of interest is the length of the line *B C* as compared with the height *A B*, or

---

adds: 'Hence one result of the unsystematic registration of the rainfall in the Central Provinces is to postpone the decision of the influence of forests on rainfall in that area for another twenty years. It is only one of the many cases of the worthlessness of unsystematic observations.'"

It is of interest also to note the following from the same source:

"In the following extract from the same report Mr. Eliot refers to the observations recently undertaken in the forests of the Saharunpoor district. For the reader unacquainted with the Western Himalayas it is necessary to explain that a *rao* is a water course issuing from the hills, and having, generally, a broad, shallow bed, which consists mainly of bowlders and shingle, and is therefore quite dry or almost dry, except after a continuous heavy shower. Mr. Eliot has not mentioned that in each *rao* levels are accurately taken every year along one and the same line, in order to note the changes that may occur in the section of the *rao* in consequence of the fire conservancy of the entire basin above.

"A different method has been introduced in the Saharunpoor forest division. Twelve representative *raos*, between the Ganges and Jumna rivers, have been selected for purposes of observation by the inspector-general of forests and conservator of the school circle, and in each forest chowki a rain guage is suitably placed. Five of them are located in the forest of Sakrauda, which is neither closed to grazing nor protected from fire. The rainfall measurements will be made by the forest guards, and the returns submitted to the meteorological department for critical examination. These observations will probably give a valuable series of data for testing the effect of different forest conditions in modifying the amount of rainfall, and hence also probably throw some light on the general question of the influence of afforestation on rainfall."

the ratio of the width of the protected strip to the height of the obstruction. M. Becquerel says that in the Rhone Valley a hedge 2 meters (6 feet) high will protect delicate garden plants to a distance of 22 meters (70 feet). This is a ratio of 1 to 11, and this ratio is about that given in the following cases gleaned from Dr. Hough's report on forestry for 1887. Judge Whiting, of Iowa, is quoted as saying that this protection, "with almost mathematical precision, amounts to 1 rod on the ground to each foot of height" of the protecting trees. This is a ratio of 10 to 165. Mr. Barnard, of Pawnee County, Nebraska, stated that a windbreak will protect an orchard a rod for every foot in height, but Prof. Thomson wanted trees 25 feet high for every 10 rods of protection. The two latter cases relate to orchards which rise 10 or 20 feet above the surface. A probable estimate is that the forest creates a calm area on its leaward side, which is, at the ground, ten to fifteen times as wide as the forest is high. The protected area has the same relations to temperature that a glade has. The air is relatively stagnant, and temperatures rise higher in the direct sun's rays and fall lower on clear nights. Evaporation is also somewhat decreased in this space, but its chief advantage is found in the protection from injurious cold or dry winds. The rough surface of the forest must also decrease the velocity of the wind, with the result of affecting the character of a storm which passes over it, especially if the storm be small or local. Dr. Waldo has given two interesting cases where the results are due undoubtedly to several causes, one being the retarding effect on the wind of a surface of city buildings. At both New York and Boston there are three meteorological stations, one out in the harbor, the second in the city, the third fairly beyond the city (Central Park and Cambridge). The mean velocities at these three stations in order are, in percentages:

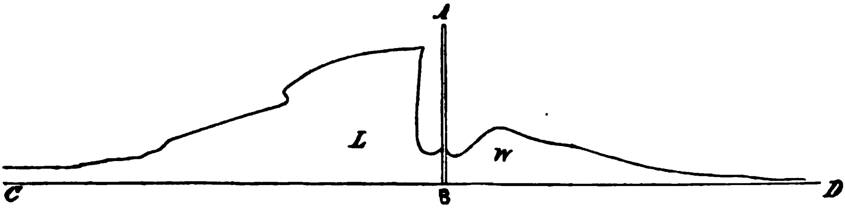


FIG. 57.—Snowbank before and behind a fence.

	Harbor.	City.	Suburbs.
New York........	1.00	0.67	0.37
Boston...........	1.00	0.67	0.33

The reduction of the velocities as one goes inland through the city is remarkable, and something similar may be expected for a wind passing over a forest.

As the interior air of the forest is generally cooler, in the warm season, than the air outside, it must be heavier, and the difference of temperature must be often so great that the heavier air will overcome the obstacles to its flow and gradually pour out near the ground. Its place will be taken by the air above which will settle, and thus there may be set up a forest circulation, as represented in the figure (Fig. 58), exactly corresponding to such a system of winds as is found in land or sea breezes, or may be found over a lake at night.

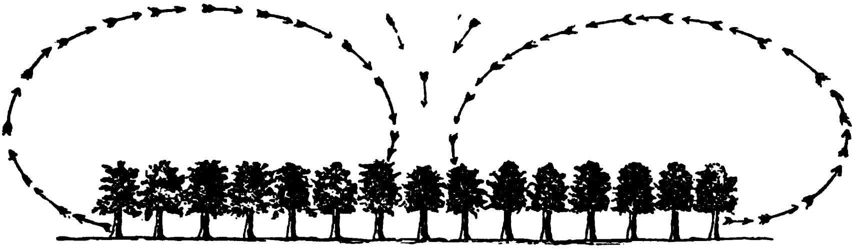


FIG. 58.—Forest circulation.

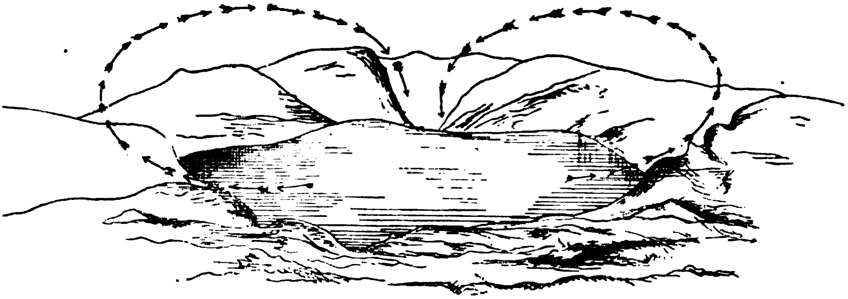


FIG. 59.—Day circulation.

During clear nights the forest air is generally warmer than that outside. When this happens a reverse circulation might be set up. This circulation must be slow, and though somewhat enlarged on by writers on the subject seems never to have been directly observed.

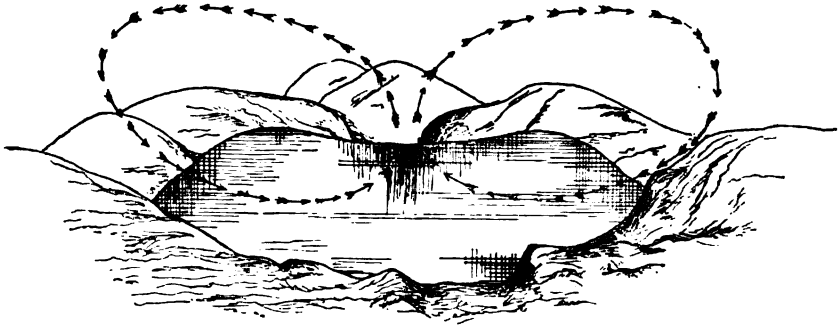


FIG. 60.—Night circulation.

INFLUENCE OF FORESTS ON FOGS AND CLOUDS.

The influence of forests on fogs and clouds has been frequently mentioned, and observed in single cases. The fog seems to linger in the woods after it has cleared off elsewhere. Trees also act as condensers,* as gatherers of dew, hoarfrost, and ice, and the latter phenomenon is especially remarkable in the so-called ice-storms, where the accumulation is so great as to overload and break the larger limbs and branches. In these cases, however, the tree acts like inorganic bodies. This is illustrated by a celebrated case on the island of Ascension, the details of which are due to Prof. Cleveland Abbe, who in 1890 personally inspected the phenomenon. This case is especially worth quoting because its records have been so badly understood. The principal water supply for the garrison of this naval station is gathered several miles away, at the summit of Green Mountain, the upper part of which has always been green with verdure since the island was discovered; almost all of this water comes from slight showers and steady dripping of trees enveloped in cloud-fog on the windward side of the mountain. Every exposed object contributes its drip; these do not condense the water; they simply collect it mechanically after it has been condensed in the uprising cooling air. Whatever fog-drops are not thus collected sweep on over the mountain and quickly evaporate again. Thirty years ago or more efforts were made to plant a few trees in the arid spot at the garrison landing; none survived, but some few new shrubs were added to the flora of the mountain top; extensive additions were also made to the mountain reservoirs and drip collectors and pipes of the aqueduct system. The few artificial scrubby plants have had no influence whatever in increasing the water supply.

INFLUENCE OF FORESTS ON HAILSTORMS AND BLIZZARDS.

M. Becquerel found, by a careful study of the destructive hailstorms in some of the departments of Central France, that these storms show a marked disinclination to enter forests. On the maps of the departments studied by him he has marked the severe storms by spots of color. A glance at the maps shows how persistently the colors keep outside the forests, especially the larger ones. To controvert these views, cases of hailstorms in forests have frequently been pointed out, but the question is not of absolute but of relative immunity of forests from severe hailstorms, and that these cases do not affect. The subject remains where it was left by M. Becquerel. It still appears proven that in Central France hailstorms avoid forests.

Many other relations of forests to storms have been suspected and advocated. For instance, that the storm precipitation is more intense over prairies, that the heavy windstorms—such as blizzards—do not long survive the traverse across a forest area, etc., but these relations still remain in the condition of hypotheses only. Forests also have broad and important relations to the flow of water on the surface, to the protection of movable soils, and to many other features of practical importance. These are matters for discussion by engineers rather than by meteorologists.

---

*See p. 124 of this bulletin.

III.—RELATION OF FORESTS TO WATER SUPPLIES.

By B. E. Fernow.

THE TOTAL WATER SUPPLY.

The water capital of the earth consists of two parts, the fixed capital and the circulating capital. The first is represented not only in the waters on the earth, but also by the amount of water which remains suspended in the atmosphere, being part of the original atmospheric water masses which, after the rest had fallen to the cooled earth, remained suspended and is never precipitated.

The circulating water capital is that part which is evaporated from water surfaces, from the soil, from vegetation, and which, after having temporarily been held by the atmosphere in quantities locally varying according to the variations in temperature, is returned again to the earth by precipitation in rain, snow, and dew. There it is evaporated again, either immediately or after having percolated through the soil and been retained for a shorter or longer time before being returned to the surface, or, without such percolation, it runs through open channels to the rivers and seas, continually returning in part into the atmosphere by evaporation. Practically, then, the total amount of water capital remains constant; only one part of it—the circulating capital—changes in varying quantities its location, and is of interest to us more with reference to its local distribution and the channels by which it becomes available for human use and vegetation than with reference to its practically unchanged total quantity.

As to the amount of this circulating water capital we have very imperfect knowledge; in many cases an approximate estimate of the amount circulating in any given area can not be satisfactorily made with the means of measurement at command, for often the precipitation is so unevenly distributed, as in the case of local thunderstorms, that two rain gauges a short distance apart collect varying amounts; hence a record from one gauge alone would give a very erroneous idea of the rainfall over the entire area. Furthermore, when improperly situated or exposed to high winds a rain gauge may furnish quite inaccurate records, and in the majority of cases the amounts collected by the gauge will be insufficient. (See Prof. Abbe's paper in this bulletin.)

A singular illustration of these errors is presented in a hydrographic investigation of the river Rhone and its watershed. While the amount of annual discharge of the river corresponds to a rainfall of 44 inches over the watershed, the rainfall records themselves for a certain period gave a precipitation of only 27.6 inches. Even the close estimate of the waters of the Upper Elbe, according to which they drain one-fourth of the total rainfall, calculated by the ingenious methods of Prof. Studnicka, does not inspire confidence. The attempts of the United States Weather Bureau to relate river stages to rainfall measurements have also so far failed to yield satisfactory results. Again, much of the moisture which is condensed and precipitated in dews escapes our observation, or at least our measurements, entirely;[*] this is, however, so small a quantity that it may be neglected in its relation to the total precipitation.

Late investigations have brought convincing proof not only that the amount of dew is much smaller than was supposed, but also that the larger part of the deposit is derived from the moisture of the soil and not from that of the atmosphere; that, therefore, dew formation in many cases can not be considered an additional water supply, but rather an element of dissipation. While G. Dines calculated the annual amount of dew at best equivalent to 38 mm. rainfall as against 127 mm., as formerly estimated for England, Wollny, upon careful measurements, calculated it for Munich at 28 to 32 mm., or less than 3½ per cent of the total rainfall. The theories regarding dew formation, according to which the moisture is deposited from the atmosphere in a manner corresponding to the familiar phenomenon on the ice pitcher, which was first antagonized in 1833 by Gerster and later by others, among them our countryman, Stockbridge, seem in part at least incomplete and needing revision.

The distribution of the circulating water capital is influenced by various agencies. The main factor which sets the capital afloat is the sun, which, by its heat and the air currents caused by it, produces the evaporation which fills the atmosphere with vapor. Anything, therefore, that influences the intensity of insolation or obstructs the passage of winds must influence the local distribution of the water capital, and hence a forest cover, which withdraws a portion of the soil from the

---

[*] A few experiments on condensation of aqueous vapor made by L. Hampel with forest-tree leaves are of interest:

	Centigrams.
Austrian pine (four needles) condensed per day in the average	4.84
Linden (one leaf) condensed per day in the average	24.40
Oak (one leaf) condensed per day in the average	25.56
Spruce (a branchlet) condensed per day in the average	9.80

The linden, of which one leaf condensed 24.40 centigrams of dew, had 1,763 leaves. It would, therefore, if all leaves had done the same, which is, to be sure, not the case, have condensed 430 grams (nearly 1 pound).

On grass the amount of dew per year was found by G. Dines to be 27 millimeters; *i. e.*, if collected an amount corresponding to 27 millimeters (over 1 inch) height of water would have resulted.

influence of sun and wind, must have an influence, however small, on the local water conditions, which may or may not become appreciable in human economy.

The question of forest influence on water supplies may be considered under three heads, namely: (1) Influence upon precipitation or upon the distribution of atmospheric water; (2) influence upon the disposal and conservation of available water supplies; (3) influence upon the "run-off" or the distribution of terrestrial waters.

INFLUENCE OF FORESTS UPON PRECIPITATION.

The question whether forest cover has or has not an influence upon the quantity of rain or snow that will fall over a given area is discussed at length on pp. 111–117 of this bulletin and also upon additional data in my annual report for 1888. It may suffice, therefore, to state only the conclusions which may fairly be drawn from our present knowledge and experience:

(1) Finding the air strata above forest stations moister and cooler, although only slightly so, than over field stations, we would infer that the tendency to condensation over wooded areas might be greater than over open fields. Experience and measurements seem to sustain this reasoning.

(2) These cooler and relatively as well as absolutely moister air strata carried away by air currents must modify conditions near the forest and possibly increase in its neighborhood also the tendency to formation of dew and to other precipitation under certain conditions.

(3) While the forest may not everywhere increase precipitation over its own area and near it, yet the presumption is that large systems of forest growth over extensive areas alternating with open fields may establish sufficient differences in temperature and moisture conditions and in air currents to modify, if not in quantity yet in timely and local distribution, the fall.

(4) It must not be overlooked that the extent, density, height, and composition, and relative position of the forest in making it a climatic factor are important conditions, and furthermore that there are certain rain conditions prevailing in climatic zones (rainy or rain-poor localities, with periodical, seasonal, or irregular rains) which are due to cosmic influences and can not be altered, yet may be locally modified by forest cover. Hence experience in one climatic zone or under one set of conditions can not be utilized for deductions in another.

(5) Altogether the question of appreciable forest influence upon precipitation must be considered as still unsolved, with some indications, however, of its existence under certain climatic and topographical conditions in the temperate zone, especially toward the end of winter and beginning of spring.

As one of the most striking examples of an increase of precipitation, seemingly due to forest planting, the experience at Lintzel, on the Lün burg heath, may be recalled, where, with a definite increase in forest conditions over an area of 25 square miles, a regular definite increase in rainfall beyond that of neighboring stations to the extent of 22 per cent within six years was observed, and a change from a deficiency to a considerable excess over the rainfall of these other stations.

RESULTS OF OBSERVATIONS NEAR NANCY, FRANCE.

The following observations were made at two stations in the neighborhood of Nancy, France. The instruments and their disposition were identical at the different stations. A is a forest station; C, a field station; B is on the verge of the forest and at a lower level. The following table gives the amount of rainfall in centimeters for the seven years 1867, 1868, and 1872, 1873, 1874, 1875, and 1876:

Time of observation.	Station A (forest glade), 380 meters.	Station B (forest verge), 240 meters.	Station C (field), 380 meters.
	Cm.	*Cm.*	*Cm.*
February to April	15.9	16.2	14.9
May to July	18.9	17.1	16.6
August to October	20.7	17.2	15.7
November to January	21.2	18.8	17.7
Year	76.7	69.3	64.9

RESULTS OBTAINED IN BOHEMIA.

It may also be appropriate here to recall the method by which Dr. Studnicka tried to establish the influence of forest areas upon the distribution of rainfall, an account of which I reproduce here from my report for 1888:

> The latest, most valuable scientific work which has been done to decide the important but difficult question of the influence of forests on precipitation is the work of Dr. F. J. Studnicka, professor of mathematics at the University of Prague, published under the title, "Basis for a Hyetography of Bohemia," in which the results of many years of observation at seven-hundred ombrometric stations are embodied, critically shifted, and scientifically considered. The author employs a wholesale method which is quite novel, complying with Woeikoff's idea that it is necessary to reduce the observed data to a common basis for comparison. To understand the significance of these observations an inspection of the map of Bohemia will be desirable, which shows it to be a basin surrounded on all sides by high mountains.
>
> The work of ombrometric observations, although begun in Bohemia during the last century, was newly organized in 1879 or 1880, when a systematic net of ombrometric stations was instituted, and in 1885 and 1886 it was extended to over seven hundred stations, for the purpose of obtaining accurate data of the quantity and distribution of precipitation over the Kingdom. Uniform ombrometers were used and very carefully placed. As at present organized, there is one station for every 75 square kilometers (about 30 square miles). No other country, I believe, can boast such a service. Although the time of observation at most stations has been short, and the averages would have been more accurately represented by an extension of observations for ten to twelve years, yet the last four years of observations, for which

all stations furnish data, according to the author, represent two extreme and two average years, and are therefore quite useful.

The very large mass of material permitted a sifting out of doubtful observations without impairing the number of available ones for the construction of a rain map of Bohemia, showing by isohyetal lines seven rain belts or zones; the zones are arranged so that the lowest shows less than 500 mm. rainfall, the three following differ by 100 mm. each, the fifth and sixth by 200 mm., and the seventh by 300 mm.; the last showing, therefore, a rainfall of 1,200 to 1,500 mm.

The central basin divides itself into two halves by a line from north to south, running somewhat east of the middle Moldau, crossing the Elbe near the mouth of the Iser, and following the latter river; the western half showing the smaller amount of precipitation, namely, 500 to 600 mm.; the eastern with 600 to 700 mm., continuing in a small belt along the foot of the Erzgebirge and the Boehmerwald encircling the first zone.

The other isohyetal lines do not embrace continuous areas, but follow in small belts the trend of the mountains. The largest amounts of precipitation are found in belts or islands in the higher altitudes of the mountains which surround this great basin. The continuity of the zones is much interrupted, so that it would be difficult to describe them without a map.

The maximum of rainfall, with over 1,200 mm., is observed in the south, near the sources of the Moldau and Motawa; in the north, near the sources of the Elbe, Iser, and Aupa, on the range of the Schneekoppe. In regard to the distribution through the months, the experience has been confirmed that with increasing absolute height the winter precipitation increases in greater proportion than the summer precipitation, while those of spring and autumn are nearly equal.

Sufficient material was on hand from which to calculate the influence of altitude on the increase of precipitations, although for altitudes above 500 m. the material is not considered sufficiently reliable. Yet the general law is well shown that with the altitude the quantities of precipitation increase in a retarded progression. This progression is calculated by forming altitude zones from 100 to 1,000 m., grouping the stations in each, calculating the mean elevation and also the mean annual precipitation as observed for each class; then by dividing the difference of precipitation in the neighboring two zones by the difference of altitude the amount of precipitation which corresponds to each 1 m. elevation within that class is found. With this figure the average amount of rainfall which theoretically belongs to each station according to its absolute elevation can be approximated by adding to or subtracting from the mean precipitations of the class as many times this amount as the actual altitude differs from the mean.

An example will make this clear: Tetschen, for instance, is situated 150 m. above sea level. According to the table the average elevation of thirteen stations of the lowest zone, to which Tetschen belongs, is 182 m., with an average precipitation of 506 mm. Now, Tetschen has an elevation 32 m. lower than the average; its normal rainfall should therefore be $32\times0.79=25.4$ mm. less than the mean of the class; hence, theoretically, according to its altitude, the quantity of rainfall for Tetschen should be $506-25.4=480$ mm.; that is, 248 mm. less than that actually found in an eight years' average. By using the figures for the two extreme zones and dividing by 100 the mean increase of precipitation for every 100 m. elevation is found to be 69 mm.

And now comes the application of this method to our proposition. The author argues that if the actually observed rainfall differs considerably from the theoretically determined, this is an indication that special agencies are at work. He finds now that of the one hundred and eighty-six stations which he subjects to scrutiny (these offering the longest and most trustworthy observation), forty-eight show a considerable difference between the observed and the theoretically expected rainfall, and he finds also that these stations are situated in the most densely wooded portions of the Kingdom.

The increased rainfall on the forty-eight stations is so considerable that a sufficient quantity may without losing significance be ascribed to other local causes, as, for instance, height and form of a mountain range in front or back, etc. Besides, the greater amounts of rainfall at these stations have been used in calculating the averages for the altitude zones, magnifying, therefore, these averages so that the actually observed one appears really smaller than if the quantities from deforested and forest areas are compared.

Expressed in percentages of the height of precipitation, an increased rainfall is shown for several localities in very large quantities, which will allow considerable reductions for other influences without losing their significance for the main proposition. Especially important appears the fact relating to two stations near the rain minimum, which also shows this influence of the forest.

Lastly, as a matter of interest I may state that the water balance is drawn for the whole Kingdom, which is of special value because the political boundaries coincide with those of the Upper Elbe watershed; therefore it is easy to determine how much of the yearly rainfall is removed by the natural water courses. According to the calculations made for the various zones by addition, the total precipitation upon the area of 51,955.98 square kilometers (about 20,000 square miles) of the Kingdom is found to be 35,398,670 cubic meters, of which the Elbe carries about one-fourth, or 8,849,667 c. m., to the sea. This figure represents a mean rainfall for the whole country of 681 mm., while the mean of observation is 693 mm.

RESULTS OF OBSERVATIONS IN INDIA AND BRAZIL.

The following interesting observations show the remarkable influence of forest areas in tropical and subtropical countries (Annual Report, 1889). Conditions in India are exhibited in the following table:

Influence of forest areas on rainfall in India.

Name of place.	Distance from the sea.	Mean temperature.				Extreme maxima.*	Relative humidity.				Precipitation.			
		April.	May.	June.	July.		April.	May.	June.	July.	April.	May.	June.	July.
Woodless country:	*Kms.*										*Cms.*	*Cms.*	*Cms.*	*Cms.*
Lucknow	847	30.1	33.3	33.1	30.4	45.8	30	36	54	74	0.5	1.8	13.3	39.4
Benares	590	31.2	33.2	32.8	29.7	45.0	41	60	81	82	0.5	1.3	12.9	32.4
Patna	445	30.3	31.4	31.4	29.2	44.6	....	....	....	....	1.0	2.5	16.9	27.8
Barhampur	270	29.6	30.1	29.2	28.7	44.1	52	60	75	79	5.6	10.1	24.2	25.8
Wooded country:														
Goalpara	427	25.2	25.9	26.9	27.7	35.1	66	77	85	84	14.8	33.6	64.3	50.0
Sibsagar	555	23.5	25.3	28.2	28.5	35.6	81	82	83	83	25.9	30.8	39.5	40.6

* Mean of two years.

A glance at this table will show *that the presence of woods has a far greater influence in mitigating the temperature during the hot and dry months of April and May than the proximity of the sea. The same* **is true** *of the relative humidity*, especially at Sibsagar, *i. e., in the middle of the forests. Most striking is the effect of the presence of woods in the diminution of the extreme maxima. The greater or less proximity of the sea has but little effect, but as soon as we reach the wooded region the extreme maximum falls 9 degrees.* Thus in 1875 the maximum thermometer did not rise above 35.3 degrees at Goalpara, while at Lucknow there was not a single day from March 14 to June 22 on which a higher temperature had not been observed. The great humidity of the air even during the hot and dry months of April and May is the cause why, in the forests, the rains begin early in March and gradually increase in intensity until

June or July, while in the woodless plains of the Ganges the amount of rainfall suddenly increases from May to June or from June to July.

The Amazon basin.—At the present time there are in the basin of the Amazon four stations where observations are made; this river basin is the most extensive forest region on the earth. The middle and upper portion of the course of the Amazon is over 1,000 kilometers distant from the Atlantic Ocean, while it is separated by mountains from the Pacific. Were it not for the forests we ought to expect, at this distance from the sea and so near the equator, very high temperatures and great dryness. The following table shows the results of the observations:

Difference of temperatures of four stations in the basin of the Amazon.

Name of station	Height above sea.	South latitude.	Distance from Atlantic.	Temperature.			Relative humidity for the year.
				Annual mean.	Mean of hottest month.	Extreme maxima.	
	Meters.	*Degrees.*	*Kiloms.*				
Para *	....	1½	100	27.0	27.7	....	....
Manaos	37	3	1,150	*26.1	27.0	*35.7	*80
Iquitos	95	3½	2,100	24.8	25.7	33.4	83
Pernambuco †	3½	8	0	25.7	27.1	31.7	72
San Antonio on Madeira River	....	9	1,750	26.0	27.0	....	....

* Ten months, from October to July.

† Pernambuco does not belong to the Amazon basin; its means are only given for comparison with those of San Antonio. The shore line near Pernambuco is wooded, but a certain distance around the city the forests are cut down to give way to fields and sugar-cane plantations.

Thus, owing to the vast primeval forests on the Upper Amazon and its tributaries, the temperature of the hottest month and the extreme maximum are not greater than on the seacoast, and the extreme maximum is far from reaching the values sometimes observed in middle latitudes. It is also to be observed that there are few regions on the earth where the "Trades" blow with such violence as on the coasts of northern Brazil. Pernambuco is therefore subject not only to the influence of the sea but also to that of a furious trade wind. Along the lower course of the Amazon the "Trade" also blows with great force; but as soon as we turn into the side valley of one of the tributaries running in a southerly and northerly direction calm weather is found to prevail. The height and density of the forest arrests the wind. There can be no doubt that the vast tracts of forest land on the Amazon, contributing to maintain the moisture of the air and weaken its motion, increase the amount of waterfall. At Iquitos 284 centimeters fall in the course of the year. It must be remembered that Iquitos lies in a plain 2,100 kilometers from the ocean and 350 from the mountains. Nowhere on the earth is the rainfall so great under similar circumstances.

SUPPOSED INFLUENCE OF FORESTS UPON HAILSTORMS.

In this connection the claimed influence of forest areas upon hailstorms may be discussed. While in France the conclusion was reached that such influence existed, it is doubted by A. Bühler (Influence of topography and forests on frequency of hailstorms, 1890), who discusses this question on the strength of observations over the whole Kingdom of Wurtemberg through sixty years (1828-'87) in great detail. An influence either upon the frequency, intensity, or course of hailstorms, it seems, could not be established.

There is, however, in these statistics and the conclusions to be derived therefrom one factor that must not be overlooked, and which the able author does not fail to observe. It is the fact that these observations refer to a mountainous region throughout. That means that the influence which the forest areas might exercise in the distribution of hailstorms is vitiated or wiped out by the more potent influence of slope and elevation. It is, therefore, impossible to study the isolated forest influence in such regions where other known but quantitatively undetermined disturbing influences must be discounted. For such studies the plain offers a more satisfactory field. The forest on hilly or mountainous terrain is never effective by itself; it could, therefore, here only be the question whether it plays a determinative or only a subordinate part. The forest besides is not like hill and mountain, a constant and evenly effective factor, since its condition and in most cases its area is constantly changing. The author also recognizes the fact that his material does not permit the discussion of the practically important question, whether and why, as is often observed, hailclouds will pass by single fields or confined areas within the general route of the storm. The careful observations of the route and extent of a hailstorm on June 6, 1891, in Thurgau, Switzerland, recorded in Meteorologische Zeitschrift, 1891, p. 403, would also show that at least in this case, in mountainous regions and with extraordinarily violent hailstorms, no effect of forest distribution was noticeable. The writer would recall here a case of his own observation on the North German plain, where the farm of one of his relatives of 5,000 acres is on three sides surrounded by forest areas of considerable extent. The owner for a long series of years has had no damage from hail, while his neighbor, only one mile outside of this forest-inclosed district, reaps the benefit of his hail-insurance money every other year.

INFLUENCE OF FORESTS UPON THE DISPOSITION OF THE WATER SUPPLY.

(1) ELEMENTS OF DISSIPATION.

In analyzing the relation of forests to the conservation of the water supplies, we shall examine first the factors of dissipation, or those which diminish the available supply. They are represented in the quantity of water which is prevented by interception from reaching the ground, in the quantity dissipated by evaporation, in the quantity used by plants in their growth, and in transpiration during the process of growing.

Interception.

The amount of rainfall and snow which is prevented by a forest growth from reaching the soil varies considerably according to the nature of the precipitation and the kind of trees which form the forest as well as the density and age of the growth.

A light drizzling rain of short duration may be almost entirely intercepted by the foliage and at once returned to the atmosphere by evaporation; if, however, the rain continues, although fine, the water will run off at last from the foliage and along the trunks. And this amount, of which the rain-gauge takes no account, represents, according to measurements from the Austrian stations, from 8 to 14 per cent, thus reducing considerably the loss to the soil by interception.

While the careful measurements at the Swiss stations in a twelve years' average show the interception in a larch forest as 15 per cent, in a spruce forest 23 per cent, in a beech growth 10 per cent, the figures for the Prussian stations are for beech growth 24 per cent, for spruce at various stations 22 per cent, 27 per cent, and 34 per cent, respectively.

Altogether, for the rainfall conditions of the countries cited, a dense forest growth will, on the average, intercept 23 per cent of the precipitation; but if allowance be made for the water running down the trunks, this loss is reduced to not more than 12 per cent.* (See page 100 of this bulletin.)

According to A. Matthieu's observations during eleven years at Cinq-Franchées (Météorologie comparée agricole et forestière, 1878), only 8.5 per cent were retained by crowns (5.84 per cent in winter, 11 per cent in summer). The more exact observations of Riegler are compiled as follows:

Species.	Rain on crown.	Fell through the crown upon soil.	Run off trunk.	Reached soil altogether.	Lost by evaporation.	Percentage of rain reaching soil altogether.
	Liter.	*Liter.*	*Liter.*	*Liter.*	*Per cent.*	
Beech	26,021	17,068	3,343	20,411	21.8	78.2
Oak	24,273	17,873	1,387	19,260	20.7	79.3
Maple	36,901	26,384	2,198	28,582	22.5	77.5
Spruce	12,044	4,793	165	4,958	58.8	41.2

The results for spruce become vitiated by the fact that large amounts of water run off from the tips of the branches, which have an inclination away from the trunk, and which could not be measured.

The intensity of the precipitation and the condition of foliage have much to do with the amounts reaching the soil, so that sometimes practically all the rain reaches it and sometimes hardly any.

The amount of interception in the open growths which characterize many of our western forest areas would be considerably smaller, especially as the rains usually fall with great force, and much of the precipitation is in the form of snow. Although branches and foliage catch a goodly amount of this the winds usually shake it down, and consequently but very little snow is lost to the ground by interception of the foliage.

---

* The maximum rainfall observed in Germany is 4 inches in twenty-four hours and 2 inches in one hour. In Switzerland there has been recorded a rainfall of 18 inches in twenty-four hours, and 2½ inches in three-quarters of an hour. This would equal 5,000 gallons per acre. Of such falls the foliage will retain only an inappreciable amount. Intensity of rainfall in the United States becomes clear from a few records: Paterson, N. J., 1½ inches in 8 minutes; Sandy Spring, Md., 5 inches in two and one-half hours; Clear Creek, Nebr., 4.50 inches in one hour and twenty-seven minutes; Castroville, Tex., 5.80 inches in twenty-four hours; Ellsworth, N. C., 13 inches, of which 9 inches in three and one-half hours, and rainfalls from 1½ to 4 inches per twenty-four hours are quite frequently reported in almost every month, especially in the Western States.

There is also a certain amount of water intercepted by the soil cover and held back by the soil itself, which must be saturated before any of it can run off or drain away. This amount, a part of which is eventually dissipated by evaporation and transpiration, depends, of course, upon the nature of the soil and its cover, especially upon their capacity to absorb and retain water.

Altogether an appreciable amount of the precipitation does not run off or drain through the forest cover but is retained by it; yet while this is apparently a loss, we shall see further on that this moisture retained in the upper strata fulfills an important office in checking a much greater loss due to evaporation, and thus becomes an element of conservation.

Evaporation.

The loss by evaporation, after the water has reached the ground, depends in the first place upon the amount of direct insolation of the soil, and hence its temperature, which again influences the temperature of the air. The nature of the soil cover, the absolute amount of moisture in the atmosphere, and the circulation of the air are also factors determining the rate of evaporation.

A considerable amount of experimental data is available showing the rate and total quantity of evaporation in different climates and at different seasons. Recent observations made by the U. S. Signal Service and the Geological Survey show that the evaporation from a water surface on the western plains and plateaus of the United States may amount to from 50 to 80 inches, and in special localities to even 100 inches, in a year, while the rainfall (diminishing in reverse ratio) over this area is from 30 to 12 inches and less. Thus in Denver, where the maximum annual precipitation may reach 20 inches, the estimated evaporation from a water surface during one year was 69 inches.

These experiments, made by the Signal Service and the Geological Survey, have thus far referred only to the rate of evaporation from water surfaces; the much more difficult question of the rate of evaporation from soil surfaces has been the subject of tentative experiment, but as yet without such results as can here be generalized.

If the loss by evaporation from an open field be compared with that of a forest-covered ground, it will, as a matter of course, be found to be less in the latter case, for the shade not only reduces the influence of the sun upon the soil, but also keeps the air under its cover relatively moister, therefore less capable of absorbing moisture from the soil by evaporation. In addition, the circulation of the air is impeded between the trunks, and this influence upon available water supply, *the wind-breaking power of the forest*, must be considered as among the most important factors of water preservation. Especially is this the case on the Western plains and on those Western mountain ranges bearing only a scattered tree growth and where, therefore, the influence of shade is but nominal.

The evaporation under the influence of the wind is dependent not only on its dryness, but also on its velocity, which being impeded, the rate of evaporation is reduced.

Interesting experiments for the purpose of ascertaining the changes in the rate of evaporation effected by the velocity of the wind were made by the Signal Service in 1887. The result of these experiments (made with Piche's hygrometers whirled around on an arm 28 feet in length, the results of which were compared with those from a tin dish containing 40 cubic centimeters of water exposed under shelter) show that with the temperature of the air at 84 degrees and a relative humidity of 50 per cent, evaporation at 5 miles an hour was 2.2 times greater than in a calm; at 10 miles, 3.8; at 15 miles, 4.9; at 20 miles, 5.7; at 25 miles, 6.1, and at 30 miles the wind would evaporate 6.3 times as much water as a calm atmosphere of the same temperature and humidity.

Now, if it is considered that the average velocity of the winds which constantly sweep the Western subarid and arid plains is from 10 to 15 miles, not rarely attaining a maximum of 50 and more miles, the cause of the aridity is not far to seek and the function of the timber belt or even simple wind-break can be readily appreciated.

What the possibilities of evaporation from hot and dry winds may be can be learned from statements regarding the "Foehn," which is the hot wind of Switzerland, corresponding to the "chinook" of our Western country.

The change in temperature from the normal, experienced under the influence of the Foehn, has been noted as from 28° to 31° F. and a reduction of relative humidity of 58 per cent. A Foehn of twelve hours' duration has been known to "eat up" entirely a snow cover of 2½ feet deep.

In Denver a chinook has been known to induce a rise in temperature of 57° F. in twenty-four hours (of which 36° in five minutes) while the relative humidity sank from 100 to 21 per cent.

The degree of forest influence upon rate of evaporation by breaking the force of winds is dependent upon the extent and density of the forest, and especially on the height of the trees. For according to an elementary law of mechanics the influence which breaks the force of the wind is felt at a considerable elevation above the trees. This can be practically demonstrated by passing along a timber plantation on the wind-swept plains. Even a thin stand of young trees not higher than 5 feet will absolutely calm the air to a considerable distance and height beyond the shelter. Unfortunately no accurate experimental data concerning this influence are at hand. According to Becquerel, a simple hedge 6 feet in height will give protection for a distance of 70 feet; and, according to Hardy, a belt of trees every 300 feet will defend vegetation almost entirely against the action of the wind. Another authority finds for every foot in height 1 rod in distance protected. (See also p. 149 of this bulletin.)

From many reports received in this office on the effects of wind-breaks upon agricultural crops, we may quote one from a farmer in Illinois, which expresses the observations generally made:

> My experience is that now in cold and stormy winters wheat protected by timber belts yields full crops, while fields not protected yield only one-third of a crop. Twenty-five or thirty years ago we never had any wheat killed by winter frost, and every year a full crop of peaches, which is now very rare. At that time we had plenty of timber around our fields and orchards, now cleared away.

The damage done to crops by the cold, dry winter winds is mainly due to rapid evaporation, and plants are liable to suffer as much by winter as by summer drought.

This is certain, that since summer and winter drought, *i. e.*, rapid evaporation, due to the continuous dry winds, is the bane of the farmer on the plains, rationally disposed timber belts alone will do much to increase available water supply by reducing evaporation.

How the forest cover, and especially the litter of a well-kept forest, may decrease the amount of evaporation within the forest to nearly seven-eighths of that in the open has been discussed on page 99 of this bulletin. The reason for this important influence of the forest is due not only to the impeded air circulation, but also to the temperature and moisture conditions of the forest air and forest soil.

The stations of Prussia allow the following average for evaporation, the amount evaporated in the open fallow field being called 100:

	Evaporated.	Retained more than in open fallow field.
	Per cent.	*Per cent.*
Under beech growth	40.4	59.6
Under spruce growth	45.3	54.7
Under pine growth	41.8	58.2
From cultivated field	90.3	9.7

A balance calculation of the amounts of precipitation and the amounts lost by evaporation for sixteen stations at varying elevations shows that with increasing altitude the surplus of water remaining for the soil increases, the mountain forest decreasing evaporation to its minimum of 9 to 13 per cent, and leaving from 87 to 91 per cent to penetrate the soil.*

---

*This is a larger amount than that given on page 101, where the water running off the trunks of trees is counted as lost.

Stations.	Altitude.	Surplus of precipitation over evaporation.		Of precipitation evaporated.	
		In the open.	In the forest.	In the open.	In the forest.
	M.	*Mm.*	*Mm.*	*Per ct.*	*Per ct.*
Schoo	3	322.5	343.6	55	28
Fritzen	30	387.5	322.5	40	28
Hadersleben	34	495.8	481.4	35	20
Eberswalde	42	142.1	237.5	73	44
Lintzel	95	174.6	180.6	70	67
Average for the region	0–100	305.3	313.1	55	37
Kurwien	124	346.1	365.7	44	26
Marienthal	143	184.9	254.7	68	37
Hagenau	145	436.1	434.3	46	26
Average for the region	100–200	322.4	351.6	53	30
Neumath	340	328.5	510.9	60	23
Friedrichsrode	353	291.0	385.8	57	26
Average for the region	300–400	309.9	448.3	58	25
Lahnhof	602	850	685.2	24	15
Hollerath	612	717.5	490.2	26	21
Schmiedefeld	680	1,468.2	1,114.3	13	7
Carlsberg	690	718.8	839.1	27	10
Average for the region	600–700	938.7	782.2	22	13
Sonnenberg	774	1,196.4	1,093.8	15	9
Melkerei	930	1,142.1	1,196.8	19	11

Altogether, it will have to be admitted that the factor of dissipation represented in the evaporation from the ground is considerably reduced by the forest cover; and since the rate of evaporation in our Western Territories is probably the greatest element in the dissipation of moisture, the greatest attention to checking it will be necessary in the husbanding of water supplies. This check to evaporation refers not only to the preservation of the water supply where it falls, but also in the natural and artificial channels through which it may be conducted or in the reservoirs where it may be stored.

The surface exposed determines the amount of evaporation from water courses and reservoirs; but if the amount evaporated is related to the available volume of water, it will appear that the smaller and slower run loses proportionately more than the larger, which thus exhibits the value and protective character of accumulation.

Take a brook 6 feet in width and only a foot in depth; this for a length of 30 feet would contain 180 cubic feet of water. If from this surface only one-tenth of 1 inch evaporates, the amount evaporated is equal to 1.5 cubic feet or $\frac{1}{120}$ of the entire supply. On the other hand one-tenth of 1 inch evaporation from a river 60 feet broad and 12 feet deep for a length of 30 feet, containing therefore 21,600 cubic feet of water, would bring the loss to 15 cubic feet or only $\frac{1}{1440}$ of the available supplies; the loss, in proportion to the supply, being twelve times greater in the former case.

Transpiration.

All vegetation takes up a certain amount of water, a part of which is consumed in building up its body, and a still larger part returned to the atmosphere by transpiration during the process of growth.

The factor of dissipation having been fully discussed on pp. 96, 130 of this bulletin, it need not be further considered here, except to recall the conclusion that forest growth transpires considerably less than other kinds of vegetation.

Since this water is given off again to the atmosphere in the locality where it has fallen—thus enriching the atmospheric moisture—and is therefore only diverted temporarily for the purpose of doing duty in producing useful substance and retaining it in the locality where it has fallen for a longer time, transpiration may even be considered as an element of conservation.

There is still to be considered a certain amount of moisture which is retained and stored up in the body of the plant, partly as a necessary permanent constituent, partly as a temporary constituent, being evaporated when the plant dies or the wood is seasoned. The amounts thus retained vary considerably according to age, capacity for transpiration, site, soil, climate, density, slow or rapid growth, weather, seasons and even the time of the day. It is therefore almost impossible to give anything but very rough approximations, especially as also the different parts of the tree vary considerably in the amounts of water present.

The water which enters into chemical composition of the wood substance represents about 50 per cent of the weight of dry substance.

The water hygroscopically retained in the living tree varies within the wide range of from 18.6 to 51.8 per cent in the wood, while the leaves contain as much as 54 to 65, and some even over 70 per cent while living; when dry, still 10 to 12 per cent. The wood of deciduous hard woods, like oak, ash, elm, birch, beech, contain in the average 38 to 45 per cent; soft deciduous trees 45 to 55 per cent, and the conifers 52 to 65 per cent. White pine when young may show as high as 77 per cent of its weight as water, while larch, of all conifers, has the smallest water capacity, namely, 45 to 55 per cent, ranking with the deciduous soft woods.

This hygroscopic water is reduced by seasoning to 10 or 12 per cent; this amount being retained even in well-seasoned woods.

Given the entire mass of wood and foliage on an acre of forest, an approximative calculation of the total quantity of water contained in the trees will show that 56 to 60 per cent of the weight of the forest must be attributed to water, while only 44 to 40 per cent is represented by dry substance. In agricultural crops it is known that the amounts of water are still larger, reaching sometimes 95 per cent of the whole weight. The production of dry substance in a well-kept dense timber forest may amount annually to from 2,500 to 3,000 pounds per acre, leaving, then, for the hygroscopic water, 3,750 pounds, and the chemically fixed water, say, 1,250 pounds; so that for this factor of dissipation 5,000 pounds in round numbers as a maximum will suffice.

ELEMENTS OF CONSERVATION.

In discussing the elements of dissipation as to the degree of their effect under forest-cover, compared with the same elements at work in the open field, we have seen that the shade, the low temperature, the relative humidity, the absence of violent air-currents, the water capacity of the forest floor, are all acting as factors of conservation. We have seen that the quantity of water lost by evaporation—the most fruitful source of dissipation—may be more than six times as great in the open as in the forest. There is only one other element of conservation affecting water supplies which requires special mention. This is the retardation in the melting of the snow, which is due to forest-cover. According to Dr. Bühler, of Zurich, this retardation in Switzerland amounts to from five to eight days in general, and may, according to weather conditions, be several weeks, thus giving a longer period for distribution. The evergreen coniferous forest in this respect naturally does better service than the deciduous one.

Effect of forests in case of snow.

Snow will lie in the forest more evenly and continuously than on the open, wind-swept areas. Thereby not only the amount finally remaining for drainage is increased, but the soil is prevented from freezing, and is kept open for percolation when the snows melt. The retardation of the melting has been determined by Bühler in Switzerland to be from eight to fourteen days.

Mr. R. U. Piper, in his Trees of America, states that an unobstructed warm wind will dissolve the snow more than ten times as fast as when it is protected from the wind, the temperature being the same, and he adduces in verification of his statement the following experiments tried by himself: In the first, a body of snow 1 foot in depth, protected from the wind, but partially exposed to the sun, after a thaw of two weeks, was not wholly melted, while another mass 6 feet in depth, more sheltered from the sun, but fully exposed to the wind, was melted in less than a week.

In the second, equal quantities of snow were placed in vessels of the same kind and size and exposed to the same temperature, one being covered and the other having a current of air constantly passing over it. The snow in the latter vessel was melted in sixteen minutes; that in the former was not entirely dissolved at the end of eighty-five minutes.

In the third experiment, in a room with the temperature above 80°, the mercury in a thermometer rose from 32° to 80° when exposed to a warm current created by a fan, or seven times as fast as when the heated air was still.

The conservative effect of the forest-cover is especially of value on the western mountain ranges, which are liable to be swept by the chinook, dissipating as if by magic the snow-cover over which it sweeps. (See p. 133.)

Even without this specially dry wind it is well known in Colorado and other mountain districts that the regular wind sweeping over the bare slopes above timber line, or where the forest-cover is removed, while they drift the snow hither and thither, they "wear it out" at the same time. By the blowing of the wind the snow is reduced to finest particles, and, by the shifting, new surfaces are constantly exposed—two processes which greatly facilitate evaporation, and thus the snow is literally worn out.

The proposition, then, to remove the forest-cover in order to allow the drifting and compacting of the snow, from which possibly to secure a longer period of distribution, even if there were no other objection, must be considered a hazardous and ill-advised expedient.

The influence of the forest upon the condition and drifting of the snow is graphically related by Middendorff in his description of Siberia, speaking of the Buran or snowstorm characteristic of the treeless plains of tundras:

> As far as the forest reaches and impedes the action of the winds the snow lies everywhere evenly and loosely, so that in the beginning of winter one can travel only on snowshoes. As soon as the tundra is reached there is no need of snowshoes. The snow lies either like a thin carpet, or drifted together in incredible masses, so compacted as to bear man and beast, etc.

General effect of forests in reducing evaporation.

The popular notion which ascribes to the moss-cover or spongy character of the forest floor a conservative function beyond that of retarding evaporation and expediting infiltration seems to be entirely erroneous and needs revision. The idea that the moisture of the soil and the flow of springs is increased by water from the spongy cover is altogether in contradiction to physical laws, and can be shown experimentally to be a mistaken one.

Water filters through the cover by the law of gravitation until the whole mass has become fully saturated. With an addition of water it will filter through to the soil, as long as the supply continues and as long as the soil is not so saturated that it can not readily absorb any more water. At last, the supply continuing, the cover will refuse to convey it and will shed it superficially, leaving opportunity to reach the soil only where the moss-cover is interrupted. When the water supply ceases, evaporation begins above, and by capillary attraction the cover supplies its loss of water on the surface from the soil below.

To give water to the strata below, it would be necessary that these should have become dry, or at least drier than the moss-cover before the latter had lost its water. This may occur and depends naturally upon the structure and nature of the soil. If the soil is strongly fissured, thus rapidly draining the upper strata, then, if the moss-cover is still saturated and an additional pressure is exerted by water standing or falling on it, a further supply of water may be given up to the soil; if, however, the moss is only just saturated and no further access of water takes place from above, then there is no physical law by which a surrender of this saturation water to the soil could take place as long as the underlying soil is of a gravelly or nonabsorbing nature. If its nature is like clay, marl, fine sand, capable of attracting water, then the further process of water absorption depends upon the difference between the water capacity of the cover and that of the soil.

In a sand soil in which the upper strata lose their water rapidly to the lower, the moss cover, which holds water more tenaciously, can be made to give up water to the soil as long as the capacity for absorption by the sand is greater than the capacity for retention by the moss.

A loam or clay soil takes up water very slowly, but takes up a great deal before it is saturated, and the process of filtration goes on very slowly; if, therefore, a plentiful rain falls, there is formed under the moss cover a shallow, nearly saturated layer of soil, which acts as an impermeable stratum. This layer is protected by the cover against rapid surface drying, and since it gives up its water only slowly to the lower strata, it remains moist so long as the moss cover is not dry. As soon as by evaporation the cover has lost its water, the soil must give up some of its moisture by capillary attraction to supply the deficiency in the cover. It must be noted here, however, that according to Oltman's experiments moss does not take up water from an only moderately moist soil. A deficiency of moisture occurring in soil earlier than in the cover can be presumed only when the water is utilized by the roots and transpired, which is not likely to occur.

These are the extreme cases between which, in nature, many intermediary conditions occur. The litter cover does not act analogously to the moss cover or to a sponge. A difference must here be noted between the newly fallen loose litter of the previous year and the closely packed and felted litter accumulations of former years. The former allows a rapid filtration; the latter, according to Riegler's experiments, is nearly impermeable, and the water practically can enter the soil only where the litter is interrupted. The compact litter serves admirably to retard evaporation. In reality there rarely exists an uninterrupted cover of such litter or a cover of one uniform nature; open spaces, moss covers, varying thicknesses of litter cover interchange, and accordingly the water penetrates readily, while the cover performs its duty as a conserving agent against evaporation.

There is an additional conservative action of the forest floor to be noted, which will be more fully discussed further on, as an influence upon the distribution of the run-off. It is the mechanical protection which the cover affords against the compacting of the soil by the falling raindrops; by this protection the soil is kept porous, permits ready percolation, and therefore less water remains at the surface to fall a prey to evaporation.

It is, then, *the protection against evaporation alone*, due to greater relative humidity of the forest air, to the shade, to the breaking of the winds, and especially to the protective soil cover, which *makes the forest a conservator of moisture everywhere*, even where it does not by its peculiar location increase the amount of precipitation.

Springs, then, may be influenced in the amount of their discharge by a removal of the forest, not because the forest supplies them directly with more water, but because by its removal the rate of evaporation is increased.

SUMMATION OF THE CONSERVATIVE AND DISSIPATIVE INFLUENCES.

The total conservative action of the forest with reference to available water supplies, aside from an increase of precipitation, is expressed by the difference between the elements of dissipation and those of conservation; the former comprised in the loss of the water by retention or interception, evaporation, and transpiration, the latter in the protection against evaporation. This balance is known to be in favor of the forest cover in some localities and under certain given conditions; but it will have become apparent that a general statement or quantitative expression of the amount of benefit is in general quite impossible. Yet in an ingenious manner a calculation for one of the Prussian mountain districts is proposed by Dr. Weber as follows: Using the figures which are exhibited in the table on page 113 he argues that the amount of water left, over and above the amount evaporated in the open at low altitudes, deducted from the amount left over and above evaporation in the forests of high altitudes, will suffice to cover the amount of transpiration; thus, in the spruce forest at the station of Sonnenberg, the surplus of precipitation above the water needed for evaporation had been 1,093.8 mm.; deducting from this the quantity which was found remaining in the open at Schoo, and which would suffice for purposes of transpiration and plant growth, a balance for drainage of 771.3 mm. results; for the beech forests at Melkerei and Hadersleben, the calculation gave a balance of 1,176.8—495.8=681 mm. for drainage. On the average, therefore, 700 mm. of the precipitation in the mountain forest in this locality are saved for the "run-off," that is, 100,000 cubic feet of water per acre.

To get a conception of what these 100,000 cubic feet mean in the river flow, it may be stated that with average water level the Rhine above Manheim has a flow of 47,700 cubic feet per second, an amount which would be yielded by 40,000 acres of mountain forest, provided all water is drained into the river; and to keep the river continually flowing at this rate would require, on the basis of these figures obtained experimentally, a forest area of 23,472 square miles, a calculation which by no means leads to absurd results for practical probability, since the drainage area of that part of the river is in reality about 30,000 square miles, largely in forest.

I also recall here the water balance drawn for the upper Elbe River watershed on page 128, from which it appears that the river flow represents about 25 per cent of the precipitation.

The amount of river flow, to be sure, does not permit a calculation of the amounts of water originally available (after they have fallen and been diminished by the factors of dissipation) for local use in both subterranean and surface runs, since the river flow exhibits both kinds of drainage, but not at the same time. Nor do the wholesale methods sometimes employed to determine the relation of river flow to precipitation promise a solution of either that question itself nor of the question how far surface conditions of the soil have a bearing upon drainage.

A detailed study of smaller and confined catchment basins alone, like those referred to hereafter (see p. 154), will give results that may eventually lead to practicable methods of calculations.

DISTRIBUTION OF TERRESTRIAL WATERS.

The distribution of the available water supply is almost as important and often a more important factor in the economy of the water than the quantity of available supply itself, and the manner in which this distribution takes place influences considerably the ultimate availability of the supply for human use.

In discussing the distribution of the water supply it is desirable to follow the natural division of the waters into superficial and underground drainage. The surface run-off gives to brooks and rivers all their rapid variations of stage; the underground drainage gives them their permanent régime.

ANALYSIS OF DETERMINING INFLUENCES.

The proportionate division of these two classes of run-off, then, is of the highest possible importance; we will, therefore, analyze the conditions which determine their relative proportion in order to find how the forest may influence the same. It is evident that the first condition is to be found in the amount and character of the precipitation. A violent rainstorm will furnish more superficial run-off than when, the rain falling slowly, time is given for the soil to absorb it.

Rainy and rain-poor or arid climates, short and insignificant rains, short but violent, long and mild, or long, plentiful rains, also periodical, seasonal rains and irregular rainfalls—all these constitute differences in the nature and time of occurrence of the rainfall, which must necessarily affect the relative amounts of the run-off. The effect is still further complicated where the precipation is partly snow, when not only the mass of accumulated supply but also the progress of melting determine the result of the run-off.

We find, therefore, based upon this one factor, namely, the nature and time of occurrence of precipitation, differences in the run-off which are dependent upon differences in climatic conditions. Thus tropical rivers show one or two regular high stages of water according to whether they have one or two rainy seasons; in regions of equinoctial rains a spring and fall freshet is normal, while the rivers may be almost dry in summer or winter; the frequent thunderstorms in the mountains of Switzerland produce short but rapid floods during the summer, while the autumn is characterized by low water in the rivers. This climatic difference in water flow it is important not to forget when discussing the influences which may modify the discharge of waters.

W. Ule, in Meteor. Zeitschr., 1890, discusses the relation of water stages in a stream and outflow in relation to precipitation. He comes to the result that a direct relation from one to the other is impossible to find, because of the complication of other conditions, which disturb this *à priori* seemingly direct relation.

He finds that amount of precipitation and water stages, or even water stages and amount of water flow, are not proportional, so that with the same water stage different amounts may run off. If this discrepancy appears in the annual mean water flow, it is still more noticeable in the monthly means. In the river Saale the mean water stage for March, 1886, indicated a flow of 378,000,000 cu. m., while the daily measurements gave 508,000,000, or 34 per cent more. The mean water stage in March was 2.13 m., in December 2.15 m. Yet the amount of flow in the latter month was 23 per cent smaller than in the former. With the stage twice as high it was found that three times the flow resulted. From these more detailed measurements it appears that changes in the amount of river flow are not necessarily due to changes in amount of precipitation.

In 1886 the amount of river flow was 14 per cent less than in 1884, although the precipitation was by 1 per cent less in 1884.

The greatest influence on river flow is assigned to the distribution through the year of the precipitation, at least in regions with persistent frost periods, where, as in the Saale catchment basin, the river flow in winter is three times as great as in summer, namely, 51 per cent of the precipitation in winter against 17.3 per cent in summer. Hence the annual mean river flow reflects more the winter precipitation than those of summer, as the following figures show:

	Year.		Winter.		Summer.	
	1882-83.	1884-85.	1882-83.	1884-85.	1882-83.	1884-85.
Precipitation	10,913	10,757	4,441	4,047	6,572	6,710
River flow, cubic meters, millions	4,476	3,182	3,340	2,142	1,127	840

The larger amount of flow in 1882-83 seems to depend on the fact that much precipitation fell in winter, and, at the same time, the greater percentage of flow in that winter is accounted for from the daily measurements showing repeated high rises, which, as has been shown, predicate disproportionate flow. The winter, besides, was warm: most of the precipitation was rain; or, if snow, was quickly melted and carried off. We see, then, that, besides the local and timely distribution of precipitation, temperature, direction and strength of winds, condition of topography and soil, other dynamic influences are exhibited in the river flow, which make this as an immediate expression of condition of precipitation uncertain.

After water has reached the ground its distribution is determined, first, by the character of the topography and, second, by the nature of the soil and the surface conditions.

The topography determines the rapidity of run-off and of collection. The more diversified the country—cut into dells, coves, rills, and furrows, steeper and less steep slopes—the larger the number of runs of unequal length in which the water is collected, while the less diversified the contour the more water must be carried off in each run. Yet where the diversity of configuration is accompanied by steep slopes the run-off may be so rapid that the valley river is filled more rapidly than the river of the open plains country with even slopes of moderate inclination.

Thus, in some of the river valleys of West Virginia, the watersheds are scooped out into such an array of coves, gashes, and water courses and minor watersheds, and so steep and rapid in descent that, in spite of the forest cover, a rainfall of a few days will induce a rapid rise of the rivers, while the same amount of rain will hardly wet the ground in a prairie country like Iowa.

The second of the above-mentioned conditions determining distribution—the nature of the soil and the surface conditions—comprises a large number of separate, though related, factors. The composition, structure, and stratification of the soil itself, its water capacity, its permeability, and other physical properties; the nature of the underlying rock and its susceptibility to disintegration under the action of erosion; the surface conditions of the soil cover, whether frozen or sunbaked, cultivated or uncultivated, barren or covered with grasses or forests; these are a part of the factors which affect the distribution of the water supply and determine the proportions of surface and underground drainage.

On a given territory, then, with given geologic, topographic, and climatic conditions, the only directly variable conditions influencing the manner of drainage are those of the upper soil strata of the soil cover. We are, then, mainly concerned with the water capacity of soils and soil covers, the intensity of their water absorption, and the amounts of water which are drained through them in given times. We are interested in studying by what means the draining capacity of the soil is increased, and by what means altogether the run-off may be changed in its nature from a superficial to a subterranean one and the reverse.

WATER CAPACITY AND WATER CONDUCTIVITY OF SOILS AND SOIL-COVERS.

We must discern two kinds of water capacity in soils, namely, the absolute or minimum water capacity and the full or maximum water capacity. The former, also called "moisture coefficient" in soil analyses, is that water quantity which the soil will retain, no matter what the drainage conditions, provided the supply is not deficient. It is this water retained in the capillaries which determines the designation of the soil as moist, wet, or dry, which latter is only comparatively so. If the drainage is impeded by an impermeable layer underlying a porous, permeable surface soil, and if the slope of the impermeable layer does not favor rapid drainage, then, if additional supplies reach the soil, all interstices and largest capillaries will fill up and the amounts of water then contained in the soil represent its greatest (full or maximum) water capacity. Any surplus above this greatest water capacity is bound to drain off at once either superficially or subterraneously.

Absolute or minimum water capacity of soils according to Von Klenze.

[Volume unit, 3.5 cm. diam. by 10 cm. height.]

Soil.	Height of layer in centimeters.	Weight of water absorbed in grams.	Volume.	Relation of weight to volume.
			Per cent.	
Sand, loose	10	44.6	26.99	44.6
	20	68.0	24.04	34.0
	30	83.8	20.37	27.2
	40	92.9	17.58	23.2
Loam, fine, loose	10	43.5	48.27	43.5
	20	76.2	47.59	38.1
	30	106.8	42.68	35.6
	40	138.2	38.42	34.5
Humose lime sand, loose, fine	10	48.2	49.13	48.2
	20	79.2	47.37	39.6
	30	113.1	45.11	37.7
	40	129.2	43.60	32.3

Full or maximum water capacity of soils according to Meister.

[Volume unit 1 cubic foot.]

Soil.	Weight of water absorbed.	Volume.
	Pounds.	*Per cent.*
Clay	21.99	50.0
Loam	26.40	60.1
Humus	30.90	70.3
Peat	27.99	63.7
Garden mold	30.33	69.0
Lime	24.09	54.9
Chalk	21.74	49.5
Sand (82 per cent)	19.94	45.4
Sand (64 per cent)	28.67	65.2
Quartz sand	20.42	46.4

From the above tables it appears that with the depth of the soil the minimum water capacity varies greatly, and the same may be expected for the maximum water capacity. In sand it may sink within 15 inches to one-half of what it is at the surface, while in loam, owing to smaller capillaries, the reduction is only one-third. The finer the capillaries the more water they can keep up proportionately in balance against the force of gravity, and hence humus and garden mold, with their fine capillaries, show the greatest water capacity.

The degree of such retention, as has been shown by Prof. C. E. Hilgard and others, is also somewhat influenced by the temperature of the soil. The least retentive soil is a course quartz sand followed by finer sands, and it is increased by an addition of lime loam, or vegetable matter.

For a "second-class" Florida sand soil the "moisture coefficient" is stated by Hilgard as 1.64 per cent of its own weight, while it is 23 per cent and more in a peat soil; a pure clay rarely exceeds 12, while the moisture coefficient of calcareous clay soils rises to 15 and 20 per cent. The maximum water capacity may be many times that of the absolute water capacity, depending on structure and more or less compact stratification of the soil. According to Ebermayer, the amounts of water held may vary between 3 and 88 per cent. Dr. Raman's investigations show the maximum water capacity of sand soils of fine and medium fine texture to be from 3 to 4 per cent.

According to Prof. Schuebler at Tübingen, who experimented on soils under natural conditions:

> Sand soil may hold 25 per cent of its weight in water; loamy soil 40 per cent of its weight in water; clay loam 30 per cent of its weight in water; pure clay soil 75 per cent of its weight in water.

The most impervious soils, as was to be expected, showed the greatest retentive power, and since by compacting the soil particles the capillarity is increased, the imperviousness of such soils is increased.

Impermeable soil strata, such as loam and very fine sand, allow, when a surface run-off is readily possible, only a passing and inferior retention of water after rainfall, in springtime taking up no more than 10 or 12 per cent of their weight, while a stratum of sand of medium grain, 20 to 25 feet deep, was calculated by Raman to be capable of taking up and holding the entire annual precipitation of 24 inches.

The capillarity of sand soils of the North German plain investigated by Raman was not capable of raising the ground water higher than 1½ feet, so that the upper strata of the soil, which was within reach of ground water, did not show any greater amount of water than the soil which had no ground water to fall back upon.

Mr. F. H. King (Agric. Expr. Sta. Wisc. Ann. Rept., 1889) has investigated the water capacity of soils with special reference to the function of ground water in plant production. Six thousand observations of ground water stages under varying surface conditions show insufficiency of capillary actions to supply water for plant transpiration rapidly enough. He found that a column of 1.5 m height of natural soil (consisting of loamy marl, red clay, sandy clay, and fine sand) could hold an amount equal to 54 cm. precipitation, which is equal to three-fifths of the mean annual precipitation at the station, of which the author presumes not more than 30.5 cm. are used for an average crop of agricultural grains.

Coming now to the influence which a forest cover may have upon the water capacity of the soil, we have to record the results of Dr. E. Ebermayer, who has investigated the water capacity of a heavy loam soil, both protected and unprotected by a forest cover.

The following table contains the measured amounts of water contained in such a soil under a forest of spruce, twenty-five, sixty, and one hundred and twenty years old, and a naked soil at 16 inches (40 cm.) and 32 inches (80 cm.) depth:

Water contents of a loamy sand; results by seasons expressed in percentages of the weight of the soil.

Season.	Spruce.									Naked soil.		
	25 years old.			60 years old.			120 years old.					
	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.
Winter (January and February)	20.23	17.00	18.61	18.06	17.78	17.91	19.75	22.44	21.09	19.96	24.73	22.35
Spring (March to May)	18.62	18.02	18.32	15.29	16.28	15.78	17.47	20.83	19.15	20.66	20.51	20.58
Summer (June to August)	15.10	16.22	15.96	14.42	17.03	15.72	17.78	20.90	19.97	19.97	19.98	19.97
Fall (September to November)	16.57	17.57	17.07	13.49	16.52	15.00	14.88	19.46	17.17	20.04	20.20	20.12

These figures show that a loam soil under forest cover is apt to be drier in the depth of the root region, and that at all seasons, than in the open field at the same depth, less so under an old and scattered growth than under a younger growth or thicket.

A repetition of these experiments, in which various depths from the top to 32 inches were included, gave during two years the following averages of water capacity, expressed in percentages of the weight of the soil:

Averages of water capacity, expressed in percentages of the weight of the soil.

Depth.	Spruce.			Unshaded soil.
	25 years old.	60 years old.	120 years old.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0 to 2 inches	30.93	29.48	40.32	22.33
6 to 8 inches	19.19	18.99	19.30	20.62
12 to 14 inches	19.10	16.07	18.28	20.54
19 to 20 inches	18.40	16.26	20.16	20.14
30 to 32 inches	17.91	17.88	21.11	20.54
Average	18.65	17.30	19.71	20.46

Ebermayer combines the values for depths from 6 inches down to 32 inches, and then concludes that the forest soil is less moist, due to the transpiration of water by plants. This conclusion is, however, not at all warranted. For if one combines the figures found in all the strata from the top to 3 inches down, they figure as follows: Spruce 25 years old, 24.79 per cent; spruce 60 years old, 23.39 per cent; spruce 120 years old, 30.01 per cent; naked soil, 22.39 per cent.

Hence, take it altogether, the naked soil contains considerably less water than the forest-covered soil. But the distribution of the water through the different layers of the soil is different in the two cases; the naked soil, due to rapid evaporation, no doubt, contains the least amounts in its upper strata, where the forest soil with its absorptive cover preserves the largest amount. Measurements of the stratum from 2 to 6 inches would probably have shown the preservative effect still more prominently.

The water capacity of soils and soil covers in general has been referred to as an element of interception. With reference to the run-off, this capacity becomes influential in determining the manner of run-off. As soon as the soil cover and the upper soil strata are saturated, and especially when the latter are more or less impermeable and the rain continues, either no water or only a small part gradually can find entrance into the soil, and the run-off becomes in the main superficial, or, if the ground be not sloping, stagnant water results.

For every watershed, no matter what its conditions, there may, therefore, come a time when the rain or snow melting continuing, the entire run-off becomes superficial, the soil being unable to take up more.

It is evident that this time must occur later in the forest than on the unforested and especially naked soil, because the water capacity of the soil cover as well as of the protected soil in the forest is greater than that of the naked soil or that covered with field crops.

The water capacity of litter, which Wollny investigated, depends on its nature and, of course, its thickness to a certain degree, and is quite considerable, much greater than that of soils.

The water capacity of various litters was found to be as follows in volume per cent:

Depth of litter.	Oak leaves.	Beech leaves.	Spruce litter.	Pine litter.	Moss.	Calcareous sand soil.
When 2 inches deep	50.77	....	38.93	....	19.82	....
When 12 inches deep	45.42	39.78	41.65	36.28	....	24.93

No soil cover was found so variable in water contents as moss, while litter would hold two or three times as much water as moss and twice as much as the soil.

The variation of water capacity at different depths appears from the following figures:

Depth of litter.	Oak leaves.	Spruce leaves.
Two inches	50.77	38.98
Four inches	52.99	47.76
Eight inches	53.09	41.03
Twelve inches	45.42	41.65

That is to say, the increase in water capacity ceases with about 8-inch depth.

The quantity of water which the soil cover can contain appears from the following measurements of Dr. Ebermayer: On the 17th of August, 1885, after rainy weather, the moss cover in a 60-year-old spruce growth contained 72.33 per cent at the top, 76.64 per cent on the lower side, and 71.67 per cent in the humus soil beneath.

After a rainstorm lasting one and a half days, on September 9, 1885, the moss cover contained 80.45 per cent at the top, 74.61 per cent on the lower side, and 74.42 per cent in the top soil.

In this connection the following note regarding the enormous water capacity of moss covers in Alaska may be of interest:

> In the interior plateau of the Cordilleran and St. Elias regions of Alaska, according to Mr. C. W. Hayes, surface degradation is greatly retarded by the luxuriant growth of moss, which covers practically the entire surface of the country. The annual precipitation is largely confined to the winter months, and the water from the melting snow is held by the sponge-like moss, which remains saturated throughout the short but hot and dry summer. Thus, with a rainfall which, in lower latitudes, would condition an arid region, a large part of the surface is swampy, quite irrespective of slope—that is, wherever the material composing it is sufficiently compact to become impervious to water on freezing. On account of this slow and imperfect surface drainage, the slopes are not cut into the ravines and arroyas so characteristic of arid regions.

WATER CONDUCTIVITY OF SOILS.

Of still more importance for the run-off than the water capacity is the water conductivity of the soil, or the rate of water absorption—filtration.

The rapidity with which the water is conducted from above downward must necessarily influence the nature of the run-off.

Gravity tends to drain the water downward, capillarity to carry it upward; the difference of these two forces in the main must, besides the mechanical obstructions of the soil particles, determine the rapidity of drainage. Experiments to establish the rate under various conditions are very few and unsatisfactory.

The capillary conduction from below has frequently been made the subject of investigation, but the downward movement has not yet been studied with sufficient detail, and it has hardly yet been recognized by the experimenters that this depends upon the difference of gravity and capillarity as two opposed forces. According to E. Wollny's experiments in 1883 and 1884—

(1) Water is conducted downward the more rapidly the larger the soil particles (*i. e.*, the less capillary attraction exists).

(2) The noncapillary interstices of the soil accelerate the downward movement of the water (*i. e.*, the less mechanical obstruction of soil particles).

(3) In granular soil the water penetrates faster than in powdery soil (*i. e.*, penetration is the slower the denser the stratification). It is most rapid in quartz and slowest in clay; in humus at a rate between these two, but in a mixture of clay soil and humus faster than the average of the two.

(4) The rapidity of drainage in a granular soil is independent of the size of the grain.

The experiments were made with soils of varying grain in tubes 110 centimeters deep, the water dropping on top constantly. The results are exhibited in the following two tables:

Water conductivity in soil with varying size of grain.

Soils.	Water sank to a depth of—						
	After 5 minutes.	After 10 minutes.	After 15 minutes.	After 25 minutes.	After 45 minutes.	After 65 minutes.	After 120 minutes.
In soil of grain—	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
0.01 to 0.71 millimeters	8.8	12.8	16.2	21.3	30.0	36.7	52.0
0.071 to 0.114 millimeters ..	18.0	27.0	37.0	52.5	79.0	103.0	....
0.114 to 0.195 millimeters ..	28.3	48.0	65.0	96.0	....	....	....
0.175 to 0.2 millimeters	45.0	82.0	110.0	....	....	....	....
0.25 to 0.50 millimeters	84.0	....	....	....	....	....	....
Mixture of various grains .	11.0	19.0	24.5	33.2	50.8	65.5	106.0

Water conductivity in granular soils.

Soils.	Water sank to a depth of—					
	After one-half hour.	After 1 hour.	After 3 hours.	After 4 hours.	After 23 hours.	After 59 hours.
Loam powder:	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
0 to 0.25 millimeters....................	9.0	32.1	20.2	23.4	57.4	97.6
0.5 to 1.0 millimeters..................	18.8	32.2	82.4	100.0	....	....
Loam granules:						
1 to 2 millimeters	19.0	32.2	83.1	100.0	....	....
2 to 4 millimeters....................	19.3	32.0	81.5	100.0	....	....
4 to 6.75 millimeters	18.8	30.4	77.5	99.6	....	....
6.75 to 9 millimeters	18.5	31.0	80.5	100.0	....	....
Mixture....................................	4.0	8.0	11.0	19.5	24.1	100.0

According to Fesca the downward movement proceeds quickest in a dry dust, only slowly in clay soils; the same amount of water being drained through the former in one hour which it took two days to drain through the latter.

The influence of a soil cover on the physical condition of soils has been investigated directly by Wollny; he comes to the result that vegetation and cover with dead material (straw, litter, etc.) tend to preserve the loose granular structure of the soil.

The forest cover, then, has a tendency to preserve the granular, porous structure of the soil, which is favorable to filtration; and as, moreover, the roots furnish channels for unimpeded drainage, it must have the tendency, other things being equal, to allow a more rapid filtration than the naked, mostly compacted soil, or even that of a field of crops after cultivation ceases.

The temperature, too, appears to have an influence favorable to rapid filtration in the forest; for, according to Pfaff, in the field during winter three-quarters of the precipitation will sink to 2 feet depth in the soil, and not more than 10 to 30 per cent in summer.

Unless, therefore, the forest cover itself had a tendency to retard penetration, which we will see is not the case, the influence of the forest upon the intensity of water absorption would be in the direction of diminishing superficial flow and facilitating subterranean drainage.

This factor is of the utmost importance in the discussion of the causes of floods. Without a consideration of the water capacity, and still more, of the intensity of water absorption, it will never be possible to draw conclusions as to probable floods from the amount of precipitation alone.

The influence of various soil conditions and soil covers upon the amount of water that will filter through has been investigated by Wollny and Ebermayer in an extended series of experiments.

Experiments of this kind which will yield results applicable to natural conditions are exceedingly difficult to arrange, and require not only many precautions, but must be continued for a long time before generalizations can be attempted. One of Wollny's series of experiments was intended to show the influence upon filtration of a grass cover on different soils. The results calculated for 1 acre are as follows:

Kinds of soil.	Amount of filtration.	
	Fallow field.	Grass covered.
	Pounds.	*Pounds.*
Calcareous sand with humus	1,593,216	782,334
Quartz sand *	3,044,250	661,548
Loam soil*	1,529,671	59,105
Peat soil	2,048,124	405,162

* From May to November.

The grass cover, therefore, reduced considerably (by 50 per cent and more) the percolation of water. Ebermayer experimented with boxes 43 square feet surface (4 square meters) and 4 feet deep, filled with garden soil, leaving one bare, covering another with moss, and two others each planted with 6-year old plants of beech and of spruce, with the following results, arranged according to seasons:

Year.	Rain.	Filtration water in height—			
		Under beech.	Under spruce.	Under moss.	Naked soil.
1886.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
March to May	156.98	12.65	10.52	16.96	10.93
June to August	560.22	15.89	12.09	31.60	26.18
September to November	114.45	1.12	0.76	7.17	3.27
December to February	126.30	9.73	5.98	11.40	9.03
Total	957.95	39.39	29.35	67.13	49.41
1887.					
March to May	219.20	10.61	5.05	14.40	9.97
June to August	210.60	2.50	1.49	13.00	3.91

In these experiments it is remarkable how small a percentage of the rainfall was filtered through, which would lead us to look at the results with caution, namely:

Of the total rainfall was filtered—

	1886.	1887.
	Per cent.	*Per cent.*
By soil covered with moss	7	6.2
By soil naked	5.1	3.5
By soil covered with beech growth	4.1	2.9
By soil covered with spruce growth	3	1.5

In regard to the amount of filtration which various soil covers allow, we have the following very instructive results from the experiments of Wollny, in which the amounts of rain and corresponding filtration on 62 square inches surface are given:

	May to September, 1886 — total rain 28,529 grams.		April to September, 1887—total rainfall 18,652 grams.	
	Amount, grams.	Per cent of rainfall.	Amount, grams.	Per cent of rainfall.
Oak leaves:				
5 centimeters	17,591	61.7	7,894	42.3
10 centimeters	19,482	68.3	7,353	39.4
20 centimeters	21,160	74.1	12,954	69.4
30 centimeters	21,061	73.8	13,272	71.2
Spruce litter:				
5 centimeters	17,793	62.4	8,653	46.4
10 centimeters	19,277	67.5	7,356	39.4
20 centimeters	19,523	68.3	14,611	78.3
30 centimeters	19,467	68.2	13,912	74.6
Pine needles:				
30 centimeters	19,734	69.2	9,784	52.4
Moss:				
5 centimeters	14,993	52.5	7,260	38.9
Bare soil:				
30 centimeters	11,610	40.7	3,636	19.5

These figures show that a litter will filter considerably larger amounts of water than a soaked soil of the same depth, and that the moss cover allows less water to filter than the litter. This is accounted for by the soil needing a larger amount of water to supply the moisture evaporated than the litter which remains moist.

Notable is the influence which the thickness of the cover exerts upon the amounts of drain water and also the relation of the amount of precipitation to the amount of filtration.

It will be noticed that with a thicker cover to 1 foot in depth (30 centimeters) the amount of precipitation hardly changes the amount of drain water, while the lighter covers have much less power to preserve a small precipitation, for of course the amounts not drained are evaporated.

E. Ebermayer (Sickerwassermengen in verschiedenen Bodenarten Wollny 1890) from a long series of experiments comes to the conclusion that besides clay, it is especially humus, which imbibes almost all precipitation and gives up very little water below.

A layer of garden mold of 1 m. furnished only 3.2, 5.7, and 7.1 per cent filtration water from precipitation in fall, spring, and winter. "If, therefore," he says, "our earth were covered with a humus soil of 1 m. in depth, subterranean drainage would be so slim that springs would be scanty and continuously flowing springs absent."

From these experiments it would then be conceivable that the forest floor could be of such nature as to prevent rapid filtration to the soil (close uninterrupted moss carpets, or compact humus), when with sudden large masses of rain falling less water would become available for underground drainage than without the forest cover. Such conditions, however, are exceptional; the possibility of their occurrence, on the other hand, makes it necessary in every additional case to ascertain not only the nature and stratification of the soil, but also the nature of the soil cover or forest floor, before we can determine whether or not the presence of the forest is conducive to practically greater percolation.

There is another element favorable to the absorption of water by the soil, and to percolation and subterranean drainage, which, as far as I know, has not been elsewhere noted. It is the fact that snow will lie in the forest more evenly and continuously than on the unprotected surface. This element of conservation not only increases the amount finally remaining for drainage, but also prevents the soil from freezing, keeping it open for percolation when the snows melt in spring.

In open fields the snows are not only apt to be dissipated by evaporation, but the soil is more apt to become incrusted with an impermeable surface stratum which would turn over the melting snow waters into surface drainage.

It is these snow waters, preserved to the subterranean drainage, which above all account for the continuity and equality of flow in springs far away from the catchment basin, the waters that fell in the winter and melted in the spring reappearing in summer.

A further element tending to increase the amounts of subterranean drainage waters lies in the retardation of the surface flow, by which the time is lengthened during which the soil may take up and filter through rain and snow waters.

The forest floor offers such impediments to surface flow not only in greater degree than any naked soil but than any other vegetation. An advantage over other kind of vegetation is also found in the deep penetration of the roots of trees, which increases the chance for percolation, while the more compact soil cover of a green sward would be rather opposing percolation. All that has been said regarding evaporation and transpiration within and without the forest needs also be kept in mind in the discussion of the amounts of drainwaters for underground disposal.

The conclusion, then, is that in general a forest floor, although retaining much of the water in its upper strata, allows less water to run off superficially, and by rendering the soil more permeable larger amounts of water are turned into subterranean channels.

While this increase in drainage waters is the general tendency of the forest cover, geological stratification may be so favorable to drainage (deeply fissured vertical or tilted-up strata) that on the score of percolation at least the effect may become irrelevant, or it may be so unfavorable (horizontal unfissured strata) that the influence upon percolation may become practically of small value.

While underground, one part of the filtered water becomes stationary as soil moisture retained in the capillaries of the soil, and finally in part to be returned to the air by transpiration from the foilage and evaporation from the surface of the soil. The other part—the surplus above the water capacity of the soil—continues to filter through the soil, gathering into definite channels, collecting in beds or basins, and finally reappearing as springs. It is obvious that the first part can not be more than the water capacity of the entire soil layer, unless there be standing ground water which would replenish the loss by transpiration and evaporation, sustained by the soil moisture.

Now, by reasoning from the statements regarding the greater ease of percolation in soils kept granular under the protection of a forest-floor, as well as by the experiments regarding water conductivity and water capacity of soils under varying conditions, and regarding actual measurement of filtration waters from such soils, we are forced to admit that in general the quantities remaining for underground runs are not only larger in the first place, but remain so during their subterranean existence, suffering less loss by evaporation under the forest cover. This effect, especially apparent on shallow soils, will be more sensible the further away from the catchment basin the water reappears as a spring, that is, the longer the subterranean run.

FORMATION OF SPRINGS AND CONDITIONS AFFECTING THEIR FLOW.

Finally we come to a consideration of the conditions which determine the final reappearance of the underground drainage in the springs. The place where a spring appears is, of course, predicated in the first place by the structure and topography of the soil and rock strata. The question of the location of a spring is, therefore, a dynamical one, on which the soil cover can have but little influence. Yet even here, an indirect influence may be found in the amount of water to be drained, and in the looseness of the surface soil, both of which conditions would tend to produce more numerous outlets and a wider distribution of reappearing underground waters.

The following elementary explanation of the formation of springs may serve to show how geological conditions influence to a large extent the manner in which the waters falling on the watershed are distributed in underground channels, collected and discharged, and that, in spite of favorable forest conditions, a region may be poor in springs and that, without any disturbance of the forest cover, a change in the location or even in the run of springs may occur.

Springs.—A spring is water which has penetrated the soil and reappears collected on the surface. Springs are in most cases the beginnings of brooks and rivers. According to the manner in which the percolated water reaches the surface, springs may be classed as standing or running springs.

The standing or ground-water springs are such as collect water in some depression of the soil and overflow only as long as the water reaches the lower level of the outlet. Their formation is easily understood from the accompanying figure (61), in which (1) represents a hillside of massive rock, continuing under the overlying strata at *a*. The latter consists of impermeable strata (2, 2) clay, loam, marl; above this a layer of gravel of coarse sand and rock material (3), and above this a stratum of soil (4), which at X is absent, leaving an open bowl where the gravel layer becomes visible. All the rain water falling on the plateau *o p* and on the slope *o a* running down, when arriving at the impenetrable strata near *b*, will be diverted into the gravel bed and spread in this, being prevented by the underlying impermeable strata from sinking. When sufficient water is supplied the water level rises until it appears at X, and if there is an outlet over the rim of the bowl and sufficient slope of the ground the spring begins to flow, forming, it may be, the beginning of a brook.

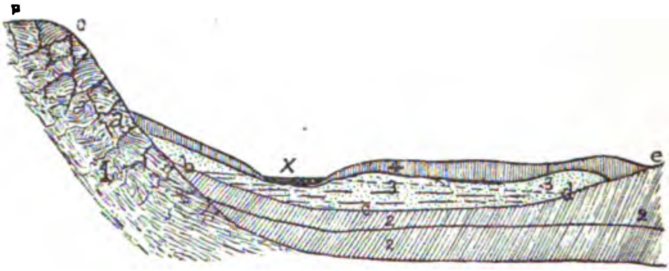


FIG. 61.—Standing or ground-water spring.

Such a standing or ground-water spring ceases to run if precipitation ceases for a length of time sufficient to reduce the water level below the outlet. Similar conditions can occur alongside of rivers when the seepage of the river supplies the water to a spring below the river level, and the level of these seepage waters rises and falls, of course, with the rise and fall of the river level.

Of running springs, there may be distinguished, according to the manner of their formation, three kinds—soil or surface springs, fissure springs, and cavern springs.

A surface spring originates when a more or less impermeable soil forms part of or lies near the upper soil stratum, allowing the water to enter only imperfectly and to an inconsiderable depth, and, passing through the looser parts of the soil, to collect and come to the surface at some point where the top soil is absent. These shallow-soil springs naturally vary quite sensibly, according to the physical conditions of the surface, and are dependent directly on the precipitation; dry up easily if it does not rain or if the soil is exposed to insolation and is deprived of shade; they are warm in summer and freeze out in winter. They are usually found in localities where the rock consists of easily disintegrated clay slates and sandstones, capped with a shallow layer of decomposed rock, or in the neighborhood of loam hills. An addition of broken rock and stones to the soil facilitates the penetration of the water and increases the comparative flow of these springs.

Whole districts along the foot of the Alps in Switzerland, Bavaria, Austria, and the Carpathians in Galicia, etc., have hardly any other kind of springs.

The second class, conveniently called "fissure" springs, originate from the waters which have deeply penetrated the soil and rock through the fissures, rents, and splits, or numberless cleavage strata of the upper rock formations, and ultimately reach a deeper lying inclined rock formation, which prevents further penetration and causes the water to run along its upper plane until the formation somewhere comes to the surface and with it the collected water of the spring. These conditions are illustrated in the accompanying cut (Fig. 62), in which *b c d e f* represents the upper fissured formations through which the rain and snow waters penetrate to the lower impermeable strata below the line *b f*, necessarily gravitating to point *f*, where the opportunity for discharging as a spring exists; a smaller spring might occur at *e*. Such conditions exist where lime or dolomite rocks overlie hard sandstones, compact clay slates, or clay beds. These springs, as a rule, are much less dependent on the changes of precipitation and temperature; they are mostly continuous and even in their flow and their temperature.

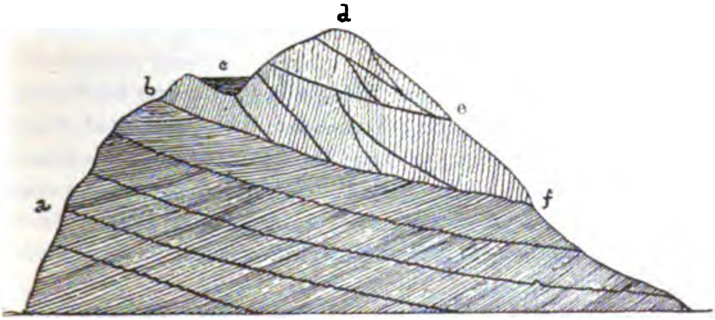


FIG. 62.—Fissure spring.

The third class of the running springs may properly be called "cavern" springs, from the fact that while their waters are drained like those of the second class, they are first collected in some subterranean basins or caverns, and appear on the surface as overflow of these basins.

In the accompanying figure (63), *a b c* is the catchment basin, from which the various fissures conduct the water *A*, overflowing at *X* into *B*, and from there overflowing and appearing at the surface at *Y*.

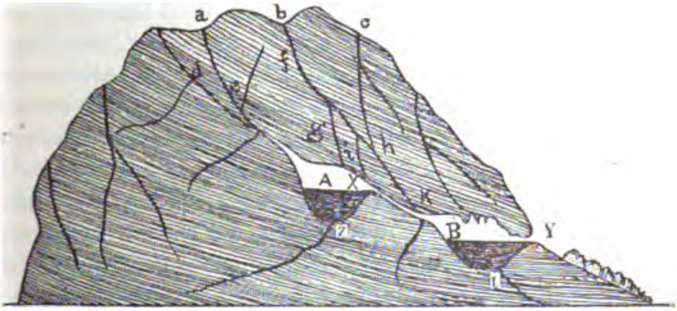


FIG. 63.—Cavern spring.

This kind of spring is found frequently in limestone formations, and since the waters of such often come from great distances from above their discharge at the surface, they are usually of very cold and even temperature; they are apt to run low when the soil is frozen and when precipitation is small; and their discharge is more or less intermittent. The obstruction of the old and opening of a new outlet by a fall of rocks at *X* and *Y*, and the widening of a formerly insignificant fissure at *z* or *t*, may reduce the flow or stop the original spring entirely, opening a new one in an entirely different part of the locality.

While we have here considered conditions under which springs are formed, there are also conditions under which their formation is excluded; such might be found in extended plains or low hill lands, with a compact, impermeable soil, which may give rise to pools and morasses, but not to springs. Plateaus of fissured limestone dolomites or of compact gneisses or granites may also be poor in springs, their waters sinking at once to such depths that no discharge is met in the immediate neighborhood of the catch-basin, or else shedding the water at once superficially.

The most direct influence of a forest cover upon the discharge would be noticeable on the surface springs, since in these the catchment area and the place of discharge lie close together, while the underground run is not only short, but lies near the surface, and hence experiences most sensibly the effect of the protection against evaporation which the forest cover offers. Deforestation here would no doubt reduce or cut off discharge entirely.

In cavern springs an influence could be exercised only in the indirect manner, by the increase of filtration over the catchment basin. The same pertains to fissure springs, whose sources of supply are usually quite removed from evaporative influences, and only where these come nearer the surface or when the spring is only small may the removal of the shade of forest cover reduce the outflow.

With reference to ground-water springs, which come to light at a considerable distance from the catchment basin, the conditions of the latter as far as the influence, increase, and preservation of water supplies, and of the area over and under which the waters run collect, is of considerable importance, while the surface condition of the area within which the spring lies (*a e* of Fig. 61), if of impermeable strata, is of less consequence, except that a forest growth may lower the ground-water level by transpiration, should the water quantities furnished from the catchment basin not be continuous and sufficient. If these strata consist of permeable soil, they would act as a second catchment basin, and the effect of the soil cover upon the quantity of drain waters (precipitation, evaporation, and transpiration) would be directly noticeable. We have seen that the tendency of the forest cover—trees, foliage, litter, moss—is to change a certain amount of surface drainage into subterranean drainage, or, in other words, to reduce the surface waters where they have fallen. Eventually, however, the subterranean waters come to the surface again, and add their stores to the surface waters, that are carried away in open runs, brooks, and rivers. Finally, then, all the water that falls on the catchment basin, except that which is returned to the atmosphere by transpiration or evaporation, becomes surface water; but the manner in which it runs off is the important point.

INFLUENCE OF FORESTS UPON SURFACE DRAINAGE.

Surface waters, like springs, may be considered from three points of view, namely, their quantity, the course and manner of distribution, and finally their behavior when collected in rivers. All that has been said regarding the conditions of underground drainage has, of course, a bearing upon the quantity of surface drainage. The amount of surface run-off is the complement of the amount drained off by springs, and it follows that where surface drainage is the rule the supply to springs is scanty, and *vice versa.*

It is evident that the conditions for a superficial run-off are to be found, first, in the amount and nature of precipitation, and next in the soil and suface conditions. A violent rainstorm will naturally furnish more superficial run-off than when, the rain falling slowly, time is given for the soil to absorb it; a snow cover, fallen on frozen ground, is apt when melting to shed its water over the frozen surface without penetrating the soil.

Nature of soil and soil cover and topography determine, with equal amounts of water to dispose of, what the nature of the run-off will be. An impermeable soil takes up sufficient water to make it plastic and then sheds all additional water superficially; a permeable soil continues to take up water and conducts it into the depth. This difference of behavior must influence and determine largely the conditions of any river bed; for if it run for some distance through impermeable soil even insignificant rainfalls will rapidly collect and swell the river, while the permeable soil would have taken up and held all or parts of the precipitation and would only gradually have given it up.

The topography determines the rapidity of run-off and of collection. The more diversified the country—cut into dells, coves, rills, and furrows, steeper and less steep slopes—in the greater number of runs of unequal length is the water collected, while the less diversified the contour the more water must be carried off in each run. Yet where the diversity of configuration is accompanied by steep slopes the run-off may be so rapid that the valley river is filled more rapidly than the river of the open plains country with even slopes of moderate inclination.

Thus in some of the river valleys of West Virginia the watersheds are scooped out into such an array of coves, gashes, and water courses and minor watersheds, and so steep and rapid in descent that, in spite of the forest cover, a rainfall of a few days will induce a rapid rise of the rivers, while the same amount of rain will hardly wet the ground in a prairie country like Iowa.

As regards soil and surface conditions it is obvious that the less permeable the soil or soil cover the less the absorptive capacity of the same, and the fewer mechanical obstructions are met the more water runs off superficially.

RETARDATION OF THE WATERFLOW.

It is in the first place this mechanical obstruction which a forest floor more than most other kinds of vegetation offers, which changes the distribution in time of surface waters, that constitutes the forest an influential factor in water flow.

Direct measurements as to the difference in time which it takes for water to run off from watersheds of different conditions are difficult or almost impossible, because it would be necessary that not only the same amount of water should fall upon the two areas under comparison, but also that the topography, angles of slopes, and length be the same, and a ready means of measurement be found. In fact, the absorption and obstruction to surface flow acting in the same sense, it would be impossible, and for practical purposes also irrelevant, to credit each with its separate quota of influence. We shall, therefore, have to be content with general reasoning and more or less inaccurate observations to prove this retardation of surface drainage. But without any evidence furnished by experiments, we can at once understand that the surface run-off is impeded by any kind of mechanical obstruction, such as is offered by the vegetation of a meadow or of a forest.

The great number of inequalities which the forest floor offers, in addition to the trunks and stumps and fallen trees, forces the run-off to many detours, thus retarding its flow and its collection in the open runs and brooks.

The retardation in the waterflow begins even before the rain has reached the soil, for the leaf canopy catches and reevaporates, as we have seen from 12 to 25 per cent of the total fall, and certainly retards the fall of the water to the ground, as can be readily observed; long after the rain has ceased the water keeps on dripping from the foliage. Thus, although most of the water reaches the ground at last, except in case of very light showers, yet the devious ways in which it reaches the soil makes the flow of water from a forest-covered hill longer in time than if the rain had fallen on a bare slope. As the result of a long-continued precipitation, it would be under the same conditions by an unforested slope, but this stage occurs in the forest later than on unforested soil and later still than on naked soil.

The great importance of the factor of time in surface drainage, both as regards dangers from freshets and erosion of soil, will be more readily appreciated when we remember that the dangerous waters in the mountains are generally of short duration.

A difference of 1,000 to 2,000 cubic feet of water per second from a square mile of watershed may often determine whether a dangerous flood is experienced or not. And since a square mile of moss-covered forest floor is capable of absorbing from 40,000,000 to 50,000,000 cubic feet in, say, ten minutes (a humus cover is capable of taking up 50 per cent of its own weight), nearly all of which the naked soil would give up some twelve to fifteen hours earlier, the surface conditions of the watershed must in many cases be determinative in the excesses of water flow in rivers.

This important fact should at least be recognized, that the surface conditions of the soil of a watershed are the only controllable factors in the problem.

Amount of precipitation, topography, and character of the soil are the practically unchangeable other conditions which determine the occurrence of freshets and floods. With a forest floor in good condition, small precipitations are apt to be absorbed readily and entirely prevented from running off superficially; with excessive rainfalls, topographical and soil conditions have eventually more influence than the forest floor; from steep declivities and an impermeable soil waters will be shed superficially in spite of and over the forest floor as soon as the latter is saturated at the surface.

Yet even so, a difference in the run-off will be experienced by the fact that the well-protected forest soil prevents erosion, the formation of detritus, and the carrying of débris into the runs and brooks below.

EXPERIENCE IN THE FRENCH ALPS.

By this protection of the soil the so-called torrential action of water is prevented, which, as the history of some departments in southern France has shown, is capable of devastating thousands of acres of fertile land by carrying the detritus into the valleys and depositing it there. At the same time the reforestation work of the French Government has also progressed far enough to furnish proof that the reclothing of the denuded hills is the practical remedy against these torrents.

Not only were the mountain sides themselves devastated and made useless by the destructive action of the water, but fertile farms for 200 miles from the source of the evil were ruined by the deposit of the débris, and the population pauperized and driven out.

According to M. Demontzey, forest administrator of France, it was estimated, in 1866, that the area of denuded mountain lands needing reforestation was 2,964,000 acres. The Government has taken hold of the restoration of the most-needing area, some 780,000 acres, on which so far some $10,000,000 have been expended, while private owners and communities have increased this expenditure for the repair of past follies to over $30,000,000, which is estimated to be about one-half of what is necessary.

How in our own country this erosive and destructive action of water is at work even in the hill country is thus graphically described by Mr. McGee, in speaking of the bad lands in the State of Mississippi:

> With the moral revolution of the early sixties came an industrial evolution; the planter was impoverished, his sons were slain, his slaves were liberated, and he was fain either to vacate the plantation or greatly to restrict his operations. So the cultivated acres were abandoned by thousands. Then the hills, no longer protected by the forest foliage, no longer bound by the forest roots, no longer guarded by the

balk and brush dam of the careful overseer, were attacked by raindrops and rain-born rivulets and gullied and channeled in all directions; each streamlet reached a hundred arms into the hills, each arm grasped with a hundred fingers a hundred shreds of soil, and as each shred was torn away the slope was steepened, and the theft of the next storm made easier.

So, storm by storm and year by year, the old fields were invaded by gullies, gorges, ravines, and gulches, ever increasing in width and depth until whole hillsides were carved away, until the soil of a thousand years' growth melted into the streams, until the fair acres of ante-bellum days were converted by hundreds into bad lands, desolate and dreary as those of the Dakotas. Over much of the upland the traveler is never out of sight of glaring sand wastes where once were fruitful fields; his way lies sometimes in, sometimes between, gullies and gorges—the "gulfs" of the blacks, whose superstition they arouse, sometimes shadowed by foliage, but oftener exposed to the glare of the sun reflected from barren sands. Here the road winds through a gorge so steep that the sunlight scarcely enters, there it traverses a narrow crest of earth between chasms scores of feet deep, in which he might be plunged by a single misstep. When the shower comes he may see the roadway rendered impassable, even obliterated, within a few minutes; always sees the falling waters accumulate as viscid mud torrents of brown or red, while the myriad miniature pinnacles and defiles before him are transformed by the beating raindrops and rushing rills so completely that when the sun shines again he may not recognize the nearer landscape.

This destruction is not confined to a single field nor to a single region, but extends over much of the upland. While the actual acreage of soil thus destroyed has not been measured, the traveler through the region on horseback daily sees thousands or tens of thousands of formerly fertile acres now barren sands; and it is probably within the truth to estimate that 10 per cent of upland Mississippi has been so far converted into bad lands as to be practically ruined for agriculture under existing commercial conditions, and that the annual loss in real estate exceeds the revenues from all sources. And all this havoc has been wrought within a quarter century. The processes, too, are cumulative; each year's rate of destruction is higher than the last.

The transformation of the fertile hills into sand wastes is not the sole injury. The sandy soil is carried into the valleys to bury the fields, invade the roadways, and convert the formerly rich bottom lands into treacherous quicksands when wet, blistering deserts when dry; hundreds of thousands of acres have thus been destroyed since the gullying of the hills began a quarter century ago. Moreover, in much of the upland the loss is not alone that of the soil, *i. e.*, the humus representing the constructive product of water-work and plant-work for thousands of years; the mantle of brown loam, most excellent of soil stuffs, is cut through and carried away by corrosion and sapping, leaving in its stead the inferior soil stuff of the Lafayette formation. In such cases the destruction is irremediable by human craft—the fine loam once removed can never be restored. The area from which this loam is already gone is appalling, and the rate of loss is increasing in a geometric proportion.

The formation of detritus and deposit in the river beds may also become the cause of dangerous floods in the larger streams, for the amount of rock material and soil which the rivers carry is one of the most potent factors in their water flow.

Since this detritus is deposited wherever the velocity of the water sinks below that necessary to carry it, forming sand banks and rubbish heaps which obstruct and change the direction of the run, it plays quite an important part in shaping the bed of the river, besides influencing the whole system of dependent brooks and rivers. The nature and shape of the detritus—whether fine sand or earth, smaller or larger rock masses, stones, roundish, square, or flat—cause much difference; and this in turn depends upon many conditions, geological and climatical.

According to the nature of the rock from which it is derived, the detritus appears in different shapes, and again changes in form during its further transportation by the waters in different ways, and therefore exerts a varying influence upon the run. Thus the detritus, which appears in large plates or shales, is carried more easily than the square or round rocks; the former, even when deposited, hinders the flow of water between the plates but little, and therefore gives less cause for stow water than the heavy square rocks, which resist the transportation and obstruct the flow more effectually.

Sand and gravel detritus is easily carried, easily accumulated, and again with a new flood easily removed; it offers, therefore, little resistance to the flow of water, but becomes objectionable in filling the lower channels of rivers, etc.

Clay detritus, although easily carried, is apt to compact and cement the rock detritus together, and thus becomes one of the worst impediments of water flow and is the cause of the worst dangers from flood waters.

From these examples it is apparent that two rivers, although under similar conditions of rainfall, physical conditions of soil and topography, may yet show different behavior, according to varying character of the detritus.

As we have stated in the beginning of this chapter, the underground drainage gives to rivers their permanent régime, while the surface run-off gives to them their rapid variations of stage.

According to whether a river is mainly supplied by surface waters that run in trackless courses and open runs over the slopes into its bed, or whether it is supplied by underground waters, its water conditions must follow a different course, fitful in the first, even in the second case. Few rivers depend on one of these sources of supply alone; most of them are supplied in the different parts of their course by both, so that a stream may begin as a torrent and later in its course find additional supplies from springs or ground waters—or the reverse may take place, being originated by a spring, it may have no other additions except from surface waters.

The greater the proportion of the supply by surface run-off the more liable to disturbances must be the flow. Finally in a large river, like the Ohio or Mississippi, the question of floods becomes still further complicated. For here not only the régime of the main river, but also that of all its affluents and the topographic, stratigraphic, climatic, and surface conditions of their catchment basins become elements of disturbance. Here the comparative lengths of the affluents alone may become all important, since the simultaneous or nonsimultaneous arrival of flood waters may determine the occurrence or nonoccurrence of high floods. As far as forest cover is concerned in such cases, deforestation in one of the side valleys and consequent rapid discharge may become an advantage for the water flow in the main river, by allowing its removal before the arrival of the flood waters of another affluent. In view of these considerations it would, therefore, be folly to assign to the condition of forest cover in the catchment basins an all determinative function. Nevertheless, in general the influence of favorable forest conditions in the catchment basin upon river flow can not be doubted, although it may become practically of no account in abnormal floods.

The first cause of abnormal floods is the occurrence of abnormal rainfalls or the sudden thawing of abnormal masses of snow. If the former occur after the soil has been saturated, or the latter when the soil remains frozen, the forest cover will be powerless to influence the run-off and will shed the water as rapidly almost as the open ground, although even the brief retardation of the confluence of water masses which the obstacles of a forest growth cause may be of moment.

But in its further course the drainage of this water collected in the rivers is favorably influenced by the presence of the forest, it having prevented the formation and deposition of detritus in the river bed.

The beneficial influence of the forest in case of abnormal floods can then probably be claimed only in so far as it protects the slopes against abrasion and the formation of débris or detritus with which the upper headwaters are filled, and which carried down into the rivers gives rise to sand banks and changes in the river bed which may increase the dangers of the next flood.

EXAMPLES OF THE INFLUENCE OF FORESTS ON WATER FLOW.

Besides the detail experiments, which are to furnish explanation of the physical laws upon which differences in water drainages occur, there are constantly accumulated experiences. Especially in France this question of forest influence on water flow has been answered by practical demonstrations. To bring it, however, to a final solution, special hydrographic surveys and statistics, such as are now contemplated in Germany, will be necessary. A first attempt at such a work is the hydrographic description of the Rhine, a model work compiled by the agency of the various governments whose lands border on that river, published in 1889. This, however, was too comprehensive a field, and more detail measurements and observations would promise more striking results. The conclusions from this survey, and a more detailed one of the Hauensteiner Alp in the southern Black Forest mountains, are that the comparative absence of damage from high floods in this Alp country, when compared with neighboring valleys, may be ascribed to the forest cover, occupying 51 per cent of its area, and the general observation is confirmed that the presence of well-kept large forest areas at the head waters in the mountains has a favorable influence upon the water stages in the water channels and per cent of erosion and formation of detritus to an appreciable extent.

One interesting detail hydrographic survey, which has in view to establish relation of forest cover to river, is published by Danckelman. It refers to the river Wupper, an affluent of the lower Rhine from the Rhenish state mountains. It was made in connection with the construction of a dam to regulate water supplies. Three catchment basins were under consideration, two of these, although containing 32 and 39 per cent woodland, are reported as devastated and especially robbed of their soil cover of litter and humus, the third containing near 50 per cent of well-kept dense forest.

From the detailed observations and measurements there was not observable any influence of forest conditions on the average daily and minimum flow, but in case of high water the daily flow was most decidedly influenced, namely, a diminution or retardation occurred in the well-wooded basin: in July, by 55 per cent; in August, by 34 per cent; in November, by 28 per cent; in March, by 21 per cent. It is stated in addition that the well-forested basin had a larger amount of rainfall and steeper slopes, a narrower valley, and was, therefore, comparatively more unfavorably situated.

An interesting note as to the amount of retardation which may be produced by the artificial means employed in the French Alps for regulation of waterflow, namely, forest-planting in connection with overflow dams, is given in M. Mathieu's work *Reboisement in France.*

The two basins of Faucon and Bourget were visited by a terrible downpour of rain of twenty-five minutes' duration. In the upper mountains there fell 42 millimeters, in the lower regions 12.3. The torrent of Faucon (which was in a devastated, deforested condition, but otherwise topographically similar to that of Bourget) was at once filled with flood waters which were estimated to consist of 60,000 cubic meters of water and 180,000 cubic meters of rock material or detritus, the flood subsiding in two hours.

In the torrent of Bourget, which had been reforested and corrected in its bed, a simple, somewhat turbulent run of water was observed, which at the overlow reached the height of 45 centimeters (18 inches) and lasted about three hours. The report continues:

> These facts show the importance of the forest cover. Thanks to the dense forest growth planted, the flood waters, divided in numberless runs and retarded constantly in their movement over the declivities in the upper basin, arrive only successively and little by little in the main bed, instead of those formidable masses of water and débris which, rapidly agglomerated, rush into the channel; the brooks called to replace the torrents receive only pure water; flood waters flowing off gradually and made harmless by the regulation of the torrent bed and of the slopes.

In the department of L'Herault, in the Cevennes Mountains in southern France, the following calculation was made of the amount of water retained by the forest cover after a heavy storm.

The basin of Lampy, comprising 1,600 acres, of which more than 50 per cent are under forest, the rest in grass and field (6 per cent), rests on impermeable granite and quartz rock with a layer 2 feet deep of rich humus soil. All the water falling must pass into a reservoir formed by closing the valley with a dam which stores the water to a height of 51 feet. The reservoir, nearly 100 years old, has never needed to be dug out, which is mentioned as a sign of the absence of soil erosion. When full all the water must pass over the dam in an overflow race, which permits a tolerably exact calculation of the discharge of water from this reservoir. The discharge through pipes and overflow in one year (1860) amounted to 4,060,038 cubic meters, while from the record of one rain gauge at the reservoir situated, therefore, at the base of the elevations which rise to 1,000 feet above it, the rainfall was calculated 6,837,350 cubic meters, probably on account of the position of the guage an understatement, showing, therefore, that not less than one-third and probably as much as one-half of the rainfall had been retained in the soil or evaporated.

On two days (July 28 and 29, 1863) there fell on this area of 1,600 acres, according to the rain gauge 530,500 cub. m. of rain. Before the rain the reservoir was full to high-water mark, and the overflow, the only means of discharge open, had been delivering for days 3,936 m. or 45 liters per second, which must, therefore, be considered the natural discharge of the basin.

After the rain the water level rose 8 inches and the discharge was:

		Cubic meters.
July	29, morning and evening	30,503
	30, morning and evening	28,864
	31, morning and evening	7,872
Aug.	1, morning	7,872
	2, evening	4,920
	Total in five days	80,032

At the end of the fifth day the water level had returned to its former height and the discharge the next day was again 3,936 c. m., which it maintained for three months. If we deduct from the discharge of 80,032 c. m. the water that would have been discharged during these five days without the additional rainfall, namely (5 × 3,936 =) 19,680, there remain 60,000 c. m. round, which without doubt were furnished by the two storms, and since the total fall had been at least 500,000 c. m. it follows that more than eight-ninths of the rain was absorbed and held by the soil to be delivered gradually.

In a neighboring basin, that of Salagou, of 16,761 acres extent, with just 10 per cent wooded, also on impermeable rock (permian), but the soil otherwise considerably washed and thin, observations could not be carried on with precision. But while the discharge of this much larger basin in ordinary times is calculated at not more than 20 to 25 liters per second, after a storm the discharge into the river is almost immediate and has been observed to rise to more than 600 c. m. per second.

Of examples in this country we may give the following as coming from good authorities and well substantiated.

In a report to the Chief of Engineers of the War Department in regard to a survey of the Savannah River, made by order of Congress, it is said:

> Reports upon the Savannah Valley and River at Augusta of about the year 1775 show the Savannah to have been a clear, rapid stream, full of excellent fish and subject to no sudden or marked changes of height. This was previous to the destruction of the forests and the opening of large tracts of land to the plow. Now the stream has become turbid; the fish, I am told, have nearly deserted the lower waters, and sudden and marked changes of the water level are the rule.

Maj. Charles W. Raymond, in a report to the Chief of Engineers, on the west branch of the Susquehanna River and the practicability of improving its navigation and of confining its waters, in times of great flood, to the general course of its channel, attributes as the principal cause of the excessive high and low stages of this river the progressive destruction of the forests from the mountain crests and slopes of its watershed, and in discussing the means of protecting the river valley from inundation in the future says: "Most important of all, such forests as yet remain upon areas not valuable for cultivation, especially near the head waters and the upper slopes of the basin, should be protected."

The New York Forest Commission, speaking of floods in the Adirondack region and the influences of forests in relation to them, say:

> In the uplands of the preserve there are many densely wooded tracts adjacent to others from which the forests have been stripped. The residents agree that in the former floods are unknown, while in the latter they are a yearly occurrence. Their appearance was coincident with the disappearance of the woods. It was then noticed that the bridges, which for many years had sufficed to span the streams during heavy rains, were no longer safe, and new ones with longer spans became a necessity.

They refer also to the effect of the removal of the forests in the Adirondack watersheds upon the navigation of the canals of the State and the whole system of inland commerce. They say:

> With the clearing away of the forests and the burning of the forest floor came a failure of canal supply that necessitated the building of costly dams and reservoirs to replace the natural ones which the fire and ax had destroyed. The Mohawk River, which for years had fed the Erie Canal at Rome, failed to yield any longer a sufficient supply, whereupon the Black River was tapped at Forestport, and its whole volume at that point diverted southward to assist the Mohawk in its work.

The superintendent of public works of the State has also called public attention to this subject several times. In the report for 1882 he says:

> The importance of the preservation of the woods in the Adirondack region in connection with the water supply of the canals can not be overestimated. With the continual cutting away of the forests and the burning of the forest floor the decreasing water supply has become painfully apparent Should this continue, the result on the canals would be disastrous.

Another interesting and impressive example of changes in conditions of water flow is given in connection with the Schuylkill River. During the last sixty or sixty-five years this river has shown a marked diminution in its minimum flow. In 1816 this flow was estimated at 500,000,000 gallons per day; in 1825, at 440,000,000; in 1867, at 400,000,000, and in 1874, at 245,000,000. In regard to this a commission of engineers say in their report in 1875:

> This remarkable decrease, not being accompanied by any great change in the rainfall, nor probably in the total annual discharge of the river, is no doubt largely due to the destruction of the forests in the drainage area, whereby the conservative action of the woodland has been lost, and the rainfall is permitted to descend rapidly to the bed and pass off in a succession of freshets.

In the year 1881 the State of New Hampshire established a forest commission, who were instructed to inquire, among other matters relating to the forests, into "the effect, if any, produced by the destruction of our forests upon our rainfall, and consequently upon our ponds and streams." In their report, made in 1885, the commission presented a summary of the large number of replies to their inquiries. These replies came from all parts of the State. From the summary the following citations are made:

> Beginning with the southern portion of the State, and with the town of Richmond, attention is called to a small stream there, which in 1865 furnished sufficient power for four sawmills nearly all the year, but which began to dry up with the more rapid removal of the timber occasioned by the introduction of steam as an auxiliary power. The water and the woods have disappeared together, and the same is the case in other portions of the town.
>
> In Fitzwilliam and Rindge the same results have been reached all the more rapidly because of the nearer proximity of these towns to a market. Well-known trout streams, once abundantly stocked with fish, are now dry half of the year, and the treeless ground and naked rocks along their banks and about their sources are considered a sufficient explanation.
>
> The chairman of the board of selectmen in Henniker, who has given much attention to the subject, is confident that the water in the Contocook River has decreased fully one-third within even twenty years, and that the tributaries have fallen off still more, many being nearly dry in the summer. During this period $75,000 worth of timber has been cut within this one town. In the surrounding towns, also, the timber has disappeared with equal rapidity, and the water supply has seriously decreased.
>
> The report from Bow, which covers a period of fifty years, within which most of the timber has been cut off, and that from Hopkinton, which covers a period of sixty years, both tell the same story of naked hillsides and diminished streams.
>
> At Hanover the Connecticut River for many years has been decreasing in volume, and with increasing rapidity the timber from its head waters has been floating by.
>
> In Canaan sixty-five years ago there were nine or more mills of different kinds; abundant water power all the year around; no thought of reservoirs or double dams, or precautions against drought. Canaan street, now covered with a firm, dry sod, was laid out through a swamp, impassable but for the hummocks and fallen trees, while dense forests of giant trees covered the hills. The writer who furnishes the above facts, a native of the place, returning after an absence of thirty years, found the hills and rocks bare, the springs choked up, and the mills obliged to resort to steam power or lie idle.
>
> The great mountain region of the State lies in contiguous parts of the counties of Grafton, Carroll, and Coos. The numberless streams originating in this region, protected by the primitive forest, might be thought to be beyond any disturbing causes, but such is not the case. The town of Littleton depends upon the Ammo-

noosuc for its water power, but three of its oldest citizens testify that this power has diminished one-third within fifty or sixty years. The mountain forests during this same period have been encroached upon as never before, and it is not surprising that so commonly these two facts are associated as cause and consequence.

Coos County contains more of the first growth of timber than any other portion of the State. In the midst of this region are the sources of the Connecticut, Androscoggin, Saco, and their many tributaries, and a diminished water supply at this point is felt throughout the course of these important streams. The report from Jefferson is that the older inhabitants agree that the streams are smaller than formerly. An intelligent observer at Berlin, on the Androscoggin River, makes the following important statements, covering a period of twenty-six years. Within a radius of 4 miles from his residence are eight streams or brooks and two ponds, and the water in each during the above period has materially diminished. As an illustration of the connection between the removal of the woods and this diminished supply, he adds that "six years ago he supplied his stock with water from what was then an unfailing brook, by means of an aqueduct which furnished 300 gallons per hour. Now that the trees along the stream have been destroyed by the woodman's ax and by forest fires, his water supply is cut short in summer by drought and in winter by frost. Hundreds of acres of timber have been cleared within these six years in the same vicinity."

At Lancaster, the county seat, on the Connecticut River, an old resident reports—

> an alarming decrease in the water of the streams and springs during the past sixty years, and especially during the last twenty-five years, within which period the smaller timber also has been removed. Israel's River in his boyhood was a large mill stream 8 or 10 rods wide, with sufficient water to carry a very large amount of machinery the year round. Now it is an insignificant stream, with, from May to November, not more than half the water it had fifty years ago, and not more than two-thirds there was twenty-five years ago. Other streams have suffered in the same way, and the springs have, if possible, suffered more than the streams. Many, once thought to be never-failing, are now for long periods dry. That the cutting off the forests accounts very largely for this change he considers as sure as that effect follows cause, and the result is hastened by the reckless methods in use. Instead of cutting timber that is matured, everything is cut to the size of 5 or 6 inches in diameter, and what remains is cut into firewood or burned at once, leaving a dreary waste.

In conclusion the commissioners say:

> While the statements given above prove beyond doubt the steady diminution of our water supply, and show what is the commonly received explanation of this state of things, a few of the towns heard from, and these mainly in the southern part of the State, report no very marked variation in the amount of water in ponds and streams for a considerable term of years, and an increase rather than a diminution in the amount of woodland. Much of this woodland, however, is the young growth, brush wood only, which can not for years protect the ground from the drying effects of sun and wind, as did the older woods; and, besides, from its relatively greater amount of foliage, evaporation proceeds all the more rapidly. That our wooded districts here and there are on the increase can not, however, alter the force of the facts which confirm the more commonly received opinion as to the general condition of things within our limits. If in any instances the decrease in water power has been checked or averted, it is all the more important to know how the result has been reached, that the same means may be used elsewhere. In every case this means has been connected with the preservation or restoration of the forests.
>
> On one point there is no division of opinion. It is not in the open ground, but be-

> neath the trees, that the moisture and the snow accumulate, and are slowly and surely supplied to the springs and streams, which then have a perennial flow. Let the same ground be deprived of its shade and this exposure to the sun hastens evaporation, and the rain and melting snow rapidly pass off through the water courses before any sufficient quantity can reach the permanent reservoirs under the surface. The snow on the exposed hillside may be swept off entirely by the wind; and even when any considerable portion remains, much will evaporate, and after all be lost to the soil and the springs. The soil itself is often washed off, and the exposed rocks given over to perpetual barrenness.

In confirmation of the conclusions of the New Hampshire forestry commission may be appropriately cited the statement made in the New Hampshire Geological Report (vol. I, p. 124), that when in the central and southern portions of the State the hay crop has been cut short by drought, it has been known to be above the average in the northern part, even with less rainfall, and as a reason it is claimed that the forests in the northern section have secured a better distribution of the results of rainfall and melted snow.

R. W. Piper, in his Trees of America, gives this illustration as coming under his own observation:

> Within about one-half mile of my residence there is a pond upon which mills have been standing for a long time, dating back, I believe, to the first settlement of the town. These have been kept in constant operation until about twenty or thirty years ago, when the supply of water began to fail. The pond owed its existence to a stream which has its source in the hills which stretch some miles to the south. Within the time mentioned these hills, which were clothed with a dense forest, have been almost entirely stripped of trees; and to the wonder and loss of the mill owners, the water in the pond has failed, except in the season of freshets, and, what was never heard of before, the stream itself has been entirely dry. Within the last ten years a new growth of wood has sprung up on most of the land formerly occupied by the old forest, and now the water runs through the year, notwithstanding the drought of the last few years.

A gentleman in eastern Massacnusetts makes the following statement: Having made a contract to supply an extensive nail factory with kegs in which to pack the nails made, he purchased a timber tract in southern Vermont, through which ran a stream. Upon this stream he erected a sawmill and began to cut the timber and make it into kegs. It was not long before the amount of water in the stream was lessened to such a degree that he was obliged to erect another mill below the first, and thus use the water a second time in order to maintain the requisite power for carrying on his business.

It is a well-known fact that the flow of water in the Hoosick and Housatonic rivers, in western Massachusetts, has become so irregular that the mill owners on those streams have been obliged to make storage basins in which to hold the water of the spring floods for use in the summer, or else to equip their mills with auxiliary steam engines. The result is claimed to be due to extensive deforesting.

Mr. David Thompson, of Cincinnati, said to the American Association for the Advancement of Science, in 1881:

It is not unusual to find in many localities the beds of what were once important mill-streams, waterless, except when filled by sudden freshets, and in Ohio certain streams emptying into the lake, which were once declared navigable, will not now float a canoe. Previous to 1832 Capt. Delorac, of Hamilton, Ohio, annually sent a fleet of flatboats down the Big Miami River at the spring rise; but with the destruction of the forests along that river the rise became so uncertain that the enterprise was of necessity abandoned.

A farmer in Ulster County, N. Y., gives the following testimony on the subject before us. He had cut an acre or two of trees on an elevated portion of his farm. In giving the result he says:

> My first loss was the drying up of a beautiful brook which had its source in my grove, and which ran through a number of fields, furnishing water for cattle while grazing. Five times the value of the wood I sold would have been refused for this stream. In the vicinity of the place where the timber stood the ground became dry during the summer. When rain fell it did not seem to be absorbed, the water ran down the hillsides, making great gullies and doing much damage, while the fields through which the brook flowed did not yield as good crops. I am now a strong believer in the value of woodlands on a farm.

A gentleman in Onondaga County states that the streams in that county have visibly failed since his boyhood, though he is not yet 40 years of age. There was at Conkling's Falls, he says, a grist and saw mill which in his youth had a plentiful supply of water. Then it gradually diminished. At first a spasmodic flow was marked; heavy freshets in spring, then low water in summer, until the water failed and it was necessary to run the mills by steam. So at Pratt's Falls, a few years ago the flow of water was abundant. The story was repeated there, violent freshets in spring, followed by the usual failure, until now, in summer, hardly a pailful runs over the falls. In this latter case there was formerly a swamp, some 5 or 6 miles above the falls, which has been reclaimed and all the trees and shrubs cut off. All these changes have occurred within fifteen years.

Ex-Governor Davis, of Maine, gives the following statement in regard to the effect of forest removal on the flow of streams, in a case with which he is well acquainted:

> The Kenduskeag River empties into the Penobscot at Bangor. The stream rises some 30 miles from its mouth, one branch in the town of Dexter, and another in the town of Corinna. I am told that fifty or sixty years ago there was a continuous flow of water the year round in this stream, and at the town of Kenduskeag, 12 miles northeast of Bangor, were situated large lumber mills on both sides of the stream. The water-flow was sufficient to carry them the year round. But during the past half century the land along the shores of the stream has been cleared throughout the greater part of its course. The result is that we have heavy spring freshets, also heavy freshets in the fall, sometimes doing much damage. I recollect, a dozen years ago or more, when living in the town of Corinth, through which said stream flows, almost every bridge on the stream was carried away in the month of March. Now, after the spring freshet subsides, the water falls rapidly until it dwindles to a very small stream, not one-half the amount flowing during the summer months that did fifty years ago.

Mr. Abbot Kinney, of California, an intelligent observer, gives the following recent testimony in regard to a particular field on his estate:

> This field was cleared of a dense brush growth, about 15 feet high, which, in California, is called chaparral. When first cleared the soil was quite dark in color and full of vegetable detritus.
>
> For two years no special care was required to prevent gullies forming from the rains. The rain-holding power of the field has constantly diminished, cross furrows have now to be carefully prepared and maintained during the rainy season. A sharp rain now runs off without doing much good where it formerly soaked in. The dark color has gone and the soil is now a plain red. It packs hard now, after every rain, when formerly it did not pack at all, except in a pathway. On the edge of the bluffs where the brush was left the old conditions prevail. I was doing some work along these bluff edges and found that I could shovel the dirt easily after cutting off the brush, but on the cleared land adjoining where the plow had missed, near the edge, the ground was so hard as to require a pick.

In 1885 the Ohio State Forestry Bureau issued circulars to its correspondents throughout the State making inquiries in regard to the observed influence of clearing the forests upon water supply. The replies received are published in the first annual report of the bureau and will be found quite in harmony with the testimony above given.

Such reports as these can be multiplied from every section of our country, and, while there would always remain the onus of proof that the change of waterflow and forest conditions were in casual relation, it is difficult to conceive of any other causes for these experiences over so widespread an area, than the change of surface conditions due to deforestation, especially the burning of the forest floor. However questionable the position of forest cover as a climatic factor, its relation to waterflow and soil conditions is attested by experiences in all parts of the world.

IV.—NOTES ON THE SANITARY SIGNIFICANCE OF FORESTS.*

By B. E. Fernow.

The subject of the sanitary significance of forests has been recently reviewed by Dr. E. Ebermayer, the well-known physicist at Munich. Other investigators have also contributed new material toward the discussion of the subject. Especially the two Italians, Serafini and Arata, investigated the influence of forests on the quantity of micro-organisms in the air, and Dr. Puchner investigated the contents of carbonic acid in the atmosphere under varying conditions.

Ebermayer shows that the oxygen exhalation of a forest in proportion to the consumption by man is insignificant. He figures that a family of four persons would require for respiration, in the burning of the necessary fuel, the oxygen exhaled by 2½ acres of forest. The hygienic significance of ozone he doubts. Puchner shows that the air in the forest contains generally more carbonic acid than the open, due to decomposition of litter. On the other hand, Ebermayer shows the air in the forest soil to contain less carbonic acid than that in the field soil. three-fourths times less in winter and five-sixths times in summer; this is explained by differences in moisture conditions. But, like sea and mountain air, forest air is freer from injurious gases, dust particles, and bacteria. Furthermore, the shade and the processes of assimilation and transpiration have a cooling effect in summer, a warming effect in winter, hence extremes in temperature are checked. Protection against winds and extremes of temperature which the forest offers is cited as desirable for the location of sanitaria and finally a tribute is paid to psychic influence, and the hygienic significance of the forest is pronounced as scientifically established. But of much more importance than the air is shown the forest soil, especially since cholera, typhus, yellow fever, and malaria are, according to Dr. Pettenkofer "soil diseases of miasmatic origin." In this connection a distribution must be kept in view between those organisms which are disease producers, pathogenic, and those which are more or less harmless parasites. The latter, Saprophytic bacteria, it must be kept in mind, thrive on decomposing vegetable and animal matter; but pathogenic bacteria thrive best on living organisms, although they occur also outside of them.

---

*These notes are based on the following publications:

Dr. E. Ebermayer, in Wollny, 1890: (1) Hygienic significance of forest air and forest soil. (2) Experiments regarding the significance of humus as a soil constituent and influence of forest, different soils and soil covers on composition of the air in the soil.

Dr. H. Puchner. (1) Investigations of the carbonic acid contents of the atmosphere.

Serafini and Arata: (1) Intorno all 'azione dei boschi sui mikro organismi transportati dai venti.

The conditions for the favorable development of the pathogenic bacteria Ebermayer discusses at great length. The facts are stated or established by him that the vegetable components of the forest soil contain less nutritive matter (albuminoid, potash, and phosphates and nitrates) for bacteria growth; that the temperature and moisture conditions are less favorable; that the sour humus of the forest soil is antagonistic to pathogenic bacteria; finally, that so far no pathogenic microbes have ever been found in forest soil, hence this soil may be called hygienically pure.

Only when upper soil strata dry out and a wind, forming dust, sweeps over them are microörganisms carried into the air; hence, with less air movement in the forest, we would expect fewer microbes in the forest air. This expectation is realized in the investigation of Serafini and Arata, who tabulate their countings of bacteria, derived into three classes—molds, liquefying, and nonliquefying bacteria for 40 successive days, from May 6 to July 8—and find, that with one exceptional day, one or two of these classes were always less numerous in the forest than on its outskirts and generally from twenty-three to twenty-eight times less.

With these detail investigations are in accord the general observations in India, where villages surrounded by forests are never visited by cholera, and troops are being withdrawn into forest stations in order to arrest the disease which it has been found is invited by removal of forests. Extensive moors, which exhibit similar unfavorable soil conditions, have been observed to give the same immunity from the disease. With regard to yellow fever the same observations have been made in our own country.

If it is considered, says Ebermayer, that the coma bacillus which produces cholera makes great demands in its nutrition and belongs to the most sensitive bacteria, especially sensitive against free acid, being destroyed by acid stomach juices, that when dry it dies quickly and is readily attacked by decay-producing bacteria, that it prospers best in a temperature of 86° F. to 104° F., and ceases to grow when the temperature sinks below 54° F., the protective influence of the forest is readily explained.

Malaria has been shown by Marchiafava and Celli not to be a bacterial disease, but to be produced by parasitic protozoa, called by these authors "plasmodia," which are formed in the red blood corpuscles and when inoculated upon healthy people produce the disease.

Although their exterior existence is unknown they probably also come from the soil, and probably, also, warmth or wet soil, periodically changing to dry in the upper strata, are the best conditions for their development. As long as the water covers the soil there is, therefore, no danger, which only begins with the recession of the same and the admission of air necessary for the development of the plasmodia, which accumulate then near the soil. Since they can not rise very high houses placed on hills within malarial regions or high above the ground are free from the disease.

The same reasons which make the forest conditions unfavorable to bacteria growth, namely, reduced temperature and moister soil, with more ready drainage usually, as well as the absence of dust and winds raising the same and the filtration process shown by Serafina by which the bacteria coming from the outside are reduced in number, are also reasons for the observed beneficent effect of forest plantations in malarial districts, such as the Campagna Romana.

Finally, a word on the value of larger parks in cities. While they do not, according to these expositions, purify the air directly by the function of the leaves, as has been claimed, they certainly establish air currents that may bring fresher air to the ground; but their hygienic function consists mainly in reducing the temperature by their shade and in furnishing better drainage conditions of the soil and purifying the same by absorbing the results of decomposition from animal matter, and lastly by preventing or reducing at least dust and with it bacteria in the air, keeping it purer than it would otherwise be.

APPENDIX 1.

DETERMINATION OF THE TRUE AMOUNT OF PRECIPITATION AND ITS BEARING ON THEORIES OF FOREST INFLUENCES.

By CLEVELAND ABBE.

The accurate measurement of rainfall, or the confidence to be placed in the rainfall data that are being accumulated in such great quantities, is a matter of profound importance in climatology, in engineering, and even in storm predictions. This subject excites much consideration in the public mind, since the comparison of the ancient and present condition of Asia, Europe, and America leads to many forebodings as to our own future; it is therefore eminently worthy of full treatment and critical discussion. We must be satisfied as to the degree of reliability of our data before we use them in attempting to elucidate such queries as are suggested by thoughtful men and such as were in fact discussed at a recent symposium of the Philosophical society at Washington upon the question "Do forests affect rainfall?"

On that occasion extensive statistics were presented by several members of that society, but it seemed to me that certain other fundamental questions which are discussed in this paper must be considered if we desire to get at the exact truth in regard to this matter.

The question, "Whether forests affect rainfall?" can apparently be attacked from several sides. Some are satisfied to appeal to deductive reasoning, thereby proving that the forests ought to affect rainfall, and their arguments have much plausibility. Others are satisfied to appeal to the historical evidence and quote the dried-up streams of Europe, Asia, and America, and the deserts that were once gardens. But the instrumental meteorologist and the observer who knows that rain gauges have been carefully observed here and there for the past 300 years, or since the first gauges were used by Leonardo da Vinci, still naturally look to the records of the many stations that are accessible to us and expect these to give a very definite statistical answer that can be relied on quantitatively as well as qualitatively.

Such rainfall records must be the ultimate test of the truth of any hypothesis, but the question is one of considerable difficulty, since we have to determine a small quantity by means of observations that may be liable to large errors, and it is necessary to be on our guard against fallacious reasoning and against the liability to draw conclusions finer than the data will warrant. To this end the law of errors or the calculus of probabilities must be appealed to. My present study relates principally to subjects of fundamental importance, namely, the accuracy of the individual statistics and the variability of distribution of rainfall chronologically and geographically.

RELATION OF PATTERN AND ALTITUDE OF GAUGES TO ACCURACY OF RAINFALL MEASUREMENTS.

With regard to the accuracy of rainfall measurements viewed simply as comparable data, two matters have been studied experimentally, namely, the size and style of the gauge and the altitude above ground. With regard to size, it is satisfactorily shown that no error of more than 1 per cent systematically attaches to gauges of the ordinary forms and of diameters anywhere between 4 and 44 inches. With regard to the altitude it must be conceded that for a hundred years it has been known in a general way that observations by gauges at various heights above the ground are not comparable with each other. The remarkable influence of altitude was first brought to the attention of the learned world by Heberden, who, in a memoir in the transactions of the Royal Society of London, in 1769, stated that a gauge on Westminster Abbey over 150 feet above the ground caught less than half as much as a gauge at the ground. Since his day numerous others have instituted similar observations in their respective localities. Usually they have been satisfied with observing only one or two elevated gauges, but of late years, in order to fully elucidate the subject, more elaborate measurements have been made; thus Phillips and Gray, at York, England, have observed at eight different altitudes, including the gauge on the tower of York Minster.

Bache, at Philadelphia, observed four gauges on top of a square tower, and four others on poles above them; Col. Ward, at Calne House, Wiltshire, observed ten pairs of gauges at elevations of 20 feet or less, each pair consisting of an 8-inch and a 5-inch gauge; Bates, at Castleton Moor, similarly observed ten pairs of gauges; Chrimes, at Rotherham Reservoir, six gauges at elevations of 25 feet or less; (——?) at Hawsker, four 3-inch gauges, at altitudes of 10 feet or less; Wilde, at St. Petersburg, six 10-inch gauges, at altitudes of 5 meters or less, and one at an altitude of 25 meters. A very laborious series of six or eight gauges at altitudes of 40 feet or less has, to my knowledge, been carried on for some years by Fitzgerald, at Chestnut Hill, near Boston, but the results are not yet published.

It will be seen, therefore, that abundant observational data are at hand for the elucidation of the peculiarities of the rain gauge, and the results that can be deduced from such data command our immediate attention. Whatever mystery has hitherto attached to the undoubted fact that elevated gauges catch less rain is now fully explained away. This phenomenon is of the nature of an error in the rain gauge depending upon the force of the wind that strikes it, and as will be seen, now that the knowledge of the source of error has been established, the method of correcting or preventing it becomes simple.

It will be remembered that Benjamin Franklin, upon reading Heberden's memoir, at once, in 1771, in a letter to Percivil explained his results by the hypothesis that falling cold rain drops condense the moisture they meet with in the warmer lower strata, and that Phillips, in 1834, independently revived this hypothesis as explaining the increase of rainfall. A much truer explanation had been suggested by Meikle, in the Annals of Philosophy for 1819, and by Boace (Annals of Philosophy, 1822), to the effect that the deficiency is due to the velocity of the wind and to the fact that the gauge stands as an obstacle to the wind; also Howard showed that the strength of the wind affected the higher gauge. But these minor notices seem to have produced but little effect among meteorologists, and it remains for W. B. Jevons, Phil. Mag., 1861, vol. XXII, to demonstrate that the Franklin-Phillips hypothesis was highly unsatisfactory, and in fact impossible, and that the true reason of diminution of apparent rainfall with the height of gauge is the influence of eddies of wind around the building and the mouth of the gauge. This explanation had, however, been also quite clearly pointed out by Prof. Bache, who had shown that eddies around the top of the tower affected the distribution of the rainfall on the tower. Alexander Dallas Bache and Joseph Henry were intimately associated in their scientific work as early as 1835 (and especially after Henry came to Washington, in 1847,) and the latter had adopted that which is now called Jevon's explanation, although as we have seen it was first given by Meikle, 1819, and subsequently independently arrived at by many others. This theory was definitely adopted and disseminated by Henry at least as early as 1853 in connection with his instructions to Smithsonian observers.

The essence of this explanation may be stated thus: In the case of ordinary rainfalls we invariably have the air full of large and small drops, including the finer particles that constitute a drizzling mist and the fragments of drops that are broken up by spattering. All these are descending with various velocities which, according to Stokes, depend on their size and density and the viscous resistance of the air; the particles of hail descend even faster than drops of water and the flakes of snow descend slower than ordinary drops. Now when the wind strikes an obstacle the deflected currents on all sides of the obstacle move past the latter more rapidly; therefore, the open mouth of the rain gauge has above it an invisible layer of air whose horizontal motion is more rapid than that of the wind a little distance higher up. Of the falling raindrops the larger ones may descend with a rapidity sufficient to penetrate this swiftly moving layer, but the slower falling drops will be carried over to the leeward of the gauge, and failing to enter it will miss being counted as rainfall, although they go on to the ground near by. Evidently the stronger the wind the larger will be the proportion of small drops that are carried past the gauge; or again, the larger the proportion of small drops and light flakes of snow that constitute a given shower, the more a gauge will lose for a given velocity of the wind. In brief, the loss will depend both upon the velocity of the wind and the velocity of the descent of the precipitation; therefore, a gauge will in general catch less in winter than in summer—less in a climate where light, fine rains occur than where the rains are composed of larger, heavier drops; less in a country or in a season of strong winds than of feeble winds; less when exposed to the full force of the wind by being elevated on a post than when exposed to the feebler winds near the ground.

The action of the wind in blowing the precipitation over to the leeward of the gauge depends on velocity rather than on the square of the velocity of the wind and of the raindrop, and it is aggravated by the formation of whirls or eddies within the gauge itself by reason of which light and dry snowflakes are even whirled out of the gauge after being once caught in it. Similar remarks apply to the rainfall on the top of a large square building with a flat or depressed roof; not only does the top as a whole receive less than an equal area at the ground, but the distribution of rainfall on the roof is such that the least rain falls on the windward portion and the most on the portion to leeward, while somewhere on the roof will be found a region whose average rainfall coincides with that on the ground. But the location of this region will vary with the direction and strength of the wind and the quality of the precipitation, so that we have but little assurance that any single rain gauge on the roof will represent the rainfall on the ground.

An interesting illustration of this action of the wind has been noted by me in the case of several gauges established in a cluster in a sandy region. The gauges sat on the ground, their mouths were 2 or 3 feet above the surface; and being cylindrical they offered considerable retistance to the wind. The windward gauges caught less rain than the leeward but they also caught more sand, showing that the strong winds which carried the light raindrops on beyond also stirred up the light surface sand and were just able to drop the sand into the windward gauges while carrying the rain on to the leeward gauge. In accordance with the preceding explanation all observations everywhere show that the higher gauges have the larger deficit in rain catch and still larger deficits in the snow catch, and that both deficits increase with the wind.

Mordecai states (Journal Franklin Institute, 1838, vol. XXII, p. 37) that he arranged his observations at Frankfort Arsenal to show the rain catch at the ground and on the tower 52 feet high according to the force of the wind as estimated by him on the scale 0 to 10 as used by him, and found the deficit of the tower gauge to be 0 per cent for calms and light winds, but increasing steadily up to 36 per cent for a wind of force 8.

Börnstein (Met. Zeit. Oct. 1884) arranges the catch in protected and unprotected gauges according to the velocity of the wind, and for seven months of observation obtained the following deficits in millimeters, to which I add the same converted into percentages on the assumption that the protected gauge is practically equivalent to the pit gauge. This assumption, although it is not quite correct, will not much change our results:

TABLE I.

Wind force—0 to 12.	Number of days.	Protected gauge catch.	Unprotected gauge catch.	Unprotected gauge deficit.	Unprotected gauge deficit.
		Mm.	*Mm.*	*Mm.*	*Per cent.*
0	5	3.30	3.06	0.24	7
1	37	88.34	81.44	6.90	8
2	26	70.40	63.80	6.60	9
3	15	36.62	29.89	6.73	18
4	15	43.45	39.57	3.88	8
5	1	2.50	1.50	1	40
6	1	1.76	1.38	0.38	22

The distinction between the effect of the winds in heavy rains and fine rains is very clearly brought out by Börnstein's classification of the catch on twenty-six days of fine rain and forty-three days of heavier rains; the percentages are as shown in the following table:

TABLE II.

Wind force.	43 heavy rains.		26 fine rains.	
	No. of days.	Deficit.	No. of days.	Deficit.
		Per cent.		*Per cent.*
0	....	....	4	23
1	17	6	8	25
2	13	13	6	18
3	7	14	6	46
4	6	17	2	52

Although all these preceding data, both by Mordecai and Börnstein, are limited in quantity, yet they conspire to show uniformly the same effect of the wind that is shown in an exaggerated scale when the ordinary gauge is used to catch snowfall. Similar results based on a somewhat larger series of observations are published by Wild (Repertorium for Met., vol. IX), as shown in the following Table III, which gives the percentage of catch during winter's snow and summer's rain separately for several altitudes and wind velocities:

TABLE III.

Altitude.	Low wind velocities (2 to 5 meters per second).		High velocities (6 to 9 meters per second).	
	Rainfall (Apr.-Oct.).	Snowfall. (Nov.-Dec.).	Rainfall (Apr.-Oct.).	Snowfall (Jan.-Mar.).
Meters.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0	100	100	100	100
1	95	89	94	80
2	92	86	84	82
25	81	26	56	16

These tables conclusively show the large influence of the wind on the catch of the rain, to say nothing of its influence on the catch of the snow. It is therefore evident that the annual rain precipitation as shown by gauges at various heights, although always diminishing with the altitude, will diminish in different ratios according to the peculiarities of the precipitation and the wind in that locality.

Without attempting to go into special refinements it will be sufficient for the present to study the annual catch as recorded at numerous stations. I have therefore in the following Table IV arranged the results quoted by Wild (Reportorium, vol. IX, 1885) and some others that have been published elsewhere. This table begins with the results of observations made at low altitudes and of these I have taken the average of all observations made for four years at Calne, three years at Castleton, eight years at Rotherham, and ten years at St. Petersburg with gauges of from 5 to 10 inches diameter. I have omitted the observations for two years at Hawsker with 3-inch gauges, because of the shortness of the series and the smallness of the gauge, which latter point has slightly exaggerated the percentage of loss. The combined result therefore for the 4 longer series is to show that for gauges of such size and construction as are generally used in the weather bureaus of the present day and for the average wind and snow or rain that occurs at these stations (which are in fact fair representatives of the northern portion of the temperate zone) the catch of rainfall diminishes with height of gauge, as shown by the percentage in the last column and in which, of course, the catch of the normal pit gauge is adopted as the standard.

TABLE IV.

Location.		No. of years.	Altitude.	Relative catch.
			Meters.	*Per cent.*
			0	100
Calne	5-inch and 8-inch gauges.	4	1	90
Castleton	5-inch and 8-inch gauges.	3	2	88
Rotherham	5-inch gauges	8	3	86
St. Petersburg	10-inch gauges	10	4	85
			5	85
			6	84
London: Westminster Abbey		1	9.1	77
Emden		2	11	72
St. Petersburg, Central Observatory		1	13	68
York: Museum		3	13	80
Calcutta: Alipore Observatory		7	15	87
Woodside: Walton on Thames		1	15	73
Philadelphia: Frankfort Arsenal		3	16	95
Sheerness: Waterworks		3	21	52
Whitehaven: St. James Church		10	24	66
St. Petersburg, Central Observatory		10	25	59
Paris: Astronomical Observatory		40	27	81
Dublin: Monkstown		6	27	64
Oxford: Radcliffe Observatory		8	34	59
Copenhagen: Observatory		4	36	67
London: Westminster Abbey		1	46	52
Chester: Leadworks		2	49	61
Wolverhampton: Waterworks		3	55	69
York: Minster		3	65	60
Boston: St. Botolph Church		2	79	47

For gauges higher than 6 meters this table gives the results of the individual localities. If we consider the individual figures in the latter part of this table it would seem that the diminution of rainfall with elevation of gauge is decided, but irregular; but it is proper to collect the data into a few mean values as shown in the following table, in which the three higher groups may be considered to represent the average conditions of the precipitation in the temperate zone quite as fairly as do those of the lower altitudes:

TABLE V.

Group.	No. of stations.	Altitude.	Observed deficit.	Square root of altitude.	Computed deficit.	Obs.-Comp. deficit.
		Meters.	*Per cent.*			
1	4	0	0	0.0	0	0
2	4	1	10	1.0	6	+4
3	4	2	12	1.41	8	+4
4	4	3	14	1.73	10	+4
5	4	4	15	2.00	12	+3
6	4	5	15	2.24	14	+1
7	4	6	16	2.45	15	+1
8	7	13	21	3.61	22	−1
9	7	28	36	5.29	32	+4
10	5	59	42	7.68	46	−4

If we may assume that on the average of the years and of the localities thus grouped together there is a fairly uniform average quality of precipitation, we should expect the deficiency at each altitude to have some definite relation to the velocity of the wind, and it emphasizes our conviction that the wind is the principal factor in bringing about this deficit when we find that these normal percentages are fairly represented by the simple formula: Deficit=6 per cent of the square root of the altitude expressed in meters. The adoption of the simple square root of the altitude is of course suggested by the well-known studies of Stevenson and Archibald, from which I infer that for these low altitudes the square root is a satisfactory approximation to the rate of increase of wind with altitude, while for much higher altitudes the one-fourth or other power might be preferable. The constant factor, 6 per cent, that enters this formula will of course not be understood as applicable to other gauges or velocities or qualities of precipitation than those included in the above table, but the close agreement of the computed percentages of deficiency shows that we appear to be on the right track, and that some method must be devised by which to free rainfall measures from the influence of the wind at the mouth of the gauge. We see, in fact, that the simple wind-gauge which we have trusted so long is liable to systematic error, whose magnitude is really enormous as compared with the small errors that we ordinarily investigate in connection with thermometers, barometers, and anemometers.

ELIMINATION OF ERRORS OF THE RAIN GAUGE.

Two methods are open to us by which to eliminate this error of the rain gauge. One is instrumental, the other observational.

Instrumental methods.—As before said, Profs. Bache and Henry seem, from their own observations, to have clearly apprehended the nature of the error with which the gauge is affected, and the latter was quick to suggest the remedy, namely, to so construct a gauge that it shall closely imitate the conditions of the normal exposure, or that of a gauge whose mouth is on a level with the ground, and which is, therefore, not covered over by the disturbing swift currents and eddies. The records of the Smithsonian show that Henry caused numerous experiments on this subject to be conducted after he and Espy, in 1848, inaugurated the Smithsonian system of meteorological observers. In the second volume of Henry's collected writings the reader can easily consult his discussion of the erroneous explanations and his own correct explanation of the phenomenon, and at page 262 will be found Henry's suggestion of "the shielded gauge." This shielded gauge was an ordinary small cylindrical gauge; a few inches below the mouth of this gauge a horizontal circular plate of tin 4 or 5 inches wide was soldered to it like the rim of an inverted hat; by this means he hoped to ward off the disturbing eddies which would necessarily be formed almost wholly beneath the flat rim and therefore harmless.

Although Henry's shielded gauge was described at least as early as 1853, yet I have not found as yet any records or observations made with it, though such probably exist, as Henry's suggestion was widely distributed among the Smithsonian observers.

In 1878 Prof. Nipher, of St. Louis, published the first results of his observations with his own shielded gauge, as independently invented by him. He surrounds the upper portion of the gauge by an umbelliform screen made of wire gauze; the falling rain strikes on this and breaks up, and falls down to the ground without spattering into the mouth of the gauge at the center, while the gauze sufficiently breaks up the wind currents to maintain a normal condition of the air at the mouth of the gauge. Nipher's own experiments with this gauge showed that its catch at a height of 118 feet above the ground was nearly the same as that of the ground gauge itself.

The invention of the shielded gauge gives us the required instrumental solution of our problem. Of late years Börnstein in Berlin and Wild in St. Petersburg have experimented very largely with Nipher's shielded gauge, and have reported in its favor. Hellmann, during 1887, also observed with a Nipher gauge, and finds the effect of the shielding to be very favorable, but not so much so as to make it quite equal to the ground gauge.

The good accomplished by the shields adopted by Henry, or by Nipher, can also be largely attained by a simple system of protection from wind. By "a protected gauge" I mean an ordinary gauge whose mouth is a few feet above the ground, and which is surrounded at a distance of a few feet by a fence or screen separate from the gauge, and whose top is a little above the mouth of the gauge. The protecting fence is therefore so arranged that it diminishes the wind at the mouth of the gauge without itself introducing new and violent injurious eddies. Both Börnstein, Wild, and Hellmann have experimented with such protected gauges, the protecting fence being so constructed that the angular altitude of the top of the fence as seen from the mouth of the gauge is between 20 and 30 degrees. The catch of the gauge thus protected always exceeds that of the free gauge, so that the correction to reduce it to the ground gauge is comparatively quite small, the deficit being reduced from 25 per cent down to 3 or 4.

Hellmann has also made the following interesting experiment: The roof of the Academy of Architecture in Berlin, where the Royal Prussian Meteorological Institute is temporarily domiciled, covers about 50 meters square, and is not merely flat, but depressed considerably below the rampart walls of the building; it, therefore, constitutes a grand protection to any gauge placed near the center of the roof, and accordingly Hellmann finds that in this location gauges catch more than anywhere else on the roof or the ramparts, and but little less than a gauge on the ground. His conclusion is that the Nipher, or similar protection, can nearly, but still only partly, annul the injurious influences of strong winds on the catch of the gauge.

The reduction or correction of rainfall for altitude, as it has hitherto been called, is therefore really a correction or reduction of the readings of the rain gauge for an instrumental error due to the wind.

Observational methods.—As an observational method of obtaining the true rainfall from the gauge reading, and if it is impracticable to establish a normal pit gauge in a good location, or if it be desired to determine approximately the correction to be applied to past records obtained from a gauge that still remains in the former place, the following arrangement offers a fair approximation.

If the present gauge has been standing in an open field at a few feet elevation place two or more *similar gauges* near it, and similarly located as far as obstacles are concerned, except only that one of these is to be decidedly lower than the old one and the other decidedly higher. From a comparison of the simultaneous records of any two gauges and their altitudes, we should for each separate rainfall, rather than for the monthly and annual sums, deduce the normal rainfall by the solution of two or more equations of the form:

Observed catch of gauge$=(1-x\sqrt{\text{altitude}})\times$ (desired catch of normal pit gauge).

Where x is the unknown special coefficient of deficiency due to wind at that altitude—that is to say, having two gauge catches, c_1 and c_2 for the two altitudes H_1 and H_2—we obtain the true rainfall (R) by the formulæ:

$$c_1=(1-x\sqrt{H_1})\,R$$
$$c_2=(1-x\sqrt{H_2})\,R$$

whence

$$R=\frac{c_1\sqrt{H_2}-c_2\sqrt{H_1}}{\sqrt{H_2}-\sqrt{H_1}}=c_1+\frac{1}{\sqrt{\frac{H_2}{H_1}}-1}(c_1-c)=c_1+n\,(c_1-c_2).$$

If c_1 and H_1 relate to the lower gauge we shall generally have $c_1 > c_2$ and $H_1 < H_2$ and the coefficient n will be a positive fraction, whose value is given in the following table for such combinations of units as may easily occur in practice:

TABLE VI.

Altitude of upper gauge.	Values of n for altitudes of lower gauge				
	1	2	3	4	5
2	2.414				
3	1.366	4.450			
4	1.000	2.414	6.469		
5	0.828	1.721	3.438	8.474	
6	0.689	1.366	2.414	4.450	10.485

If the present gauge is located upon the top of a building, perhaps the best that can be done to study the accuracy of its records is to locate other similar gauges so as to get the average rainfall over the whole roof at the same uniform altitude; the next best would be to establish a standard protected or shielded gauge as high as practicable above the roof.

If a new observing station is to be started then a single shielded or protected gauge is better than a single unprotected one; but two more shielded gauges at different altitudes afford the means of calculating the correction for wind which will, of course, be quite small for this style of gauge.

VARIATIONS IN GEOGRAPHICAL DISTRIBUTION OF RAINFALL.

By the combination of records from widely separated rainfall stations we ordinarily seek to determine the uniformity or irregularity of rainfall as to its geographical distribution. The study of horizontal distribution of rain should be first made by means of simultaneous observations at many stations within a small region. The most instructive work of this kind that I know of is that just now being carried on by Hellmann in the "experimental rainfall field" of the Royal Prussian Meteorological Institution. This institution was in 1884 officially transferred from the bureau of statistics, where it had been organized by Mahlmann and Dove, over to the bureau of religion, education, and medicine, where it is now intimately connected with all the scientific and educational work in Berlin and is under the directorship of Prof. W. von Bezold. The experimental rain field really consists of the city of Berlin and the country around, especially to the westward, embracing a region of about 15 kilometers square, within which are located Berlin, Spandau, and Potsdam. The forests on the westward, the intermediate gardens and fields, the valley of the river Spree, and the city of Berlin, offer a great variety of surfaces but without any mountains or hills. The average height of the ground above sea level is scarcely 50 meters, the average distance of the gauges from each other, namely, the mean of all possible combinations, is about 4.5 kilometers, the maximum distance being 11 and the minimum 0.5.

Within this area Hellmann has twenty-one stations, some of which represent several gauges. His work began in 1884, and he adopted as the standard height of the mouth of the gauge 1.07 meters above the ground. I have selected for study the eleven stations for which complete records for 1886–'87 are given in Hellmann's Reports. The accompanying Table VII shows the rainfall for each station for each year and the departures of each station from the annual mean of the eleven. From these departures we get the probable error of any one annual rainfall as plus or minus 6 per cent of its own value. That is to say, assuming that the same quantity of rain and snow fell uniformly over the whole of this small region, and that the gauges, if unaffected by any error, should therefore agree among themselves perfectly, then their failure to do so is such that it is an even chance that any given rainfall is discordant from the average by plus or minus 6 per cent. At first Hellmann suggested that the records of stations 1, 2, 3, and 4, which were in the open land east of the forests, showed that less precipitation fell there than over the forests, affording an argument for the idea that the forest attracted an extra amount of rain; but of the other stations there were also some that were protected by the forests, and next year all of these reported large rainfalls. Now, all of these gauges were at a standard height in open regions, such that only the variations in wind proper or in the currents induced by neighboring obstacles could conceivably affect the catch of the gauge; moreover the differences between the stations were greatest in the winter and least in the summer months, and all the study of the configuration of the ground around the stations tends to show that the differences in the catches of the gauges were due to the irregularities of horizontal distribution of the strength of the wind as influenced by the surroundings. In other words, instead of studying the geographical or horizontal distribution of the total annual rainfall it was safe to assume that that had been uniform for each year over this small area, and that we are studying simply the horizontal distribution of a deficiency in catch or a rain-gauge error due to very local winds at the mouths of the gauges.

TABLE VII.

Station, Hellmann's number.	Observed precipitation.		Departures.			
	1886.	1887.	1886.	1887.	1886.	1887.
	mm.	*mm.*	*mm.*	*mm.*	*Per ct.*	*Per ct.*
1	394	514	30	4	7	1
2	363	507	61	11	14	2
3	387	524	37	6	9	2
4	388	505	36	13	9	2
6	435	492	11	26	3	1
7	438	536	14	18	3	1
8	462	549	38	31	9	2
9	462	509	38	9	9	2
10	473	536	49	18	12	2
12	444	516	20	2	5	1
14	422	516	2	2	0	0
Mean	424	518	336	140		

This conclusion is confirmed by examining the records in the summer months separately from those in the winter. Local showers are frequent during the summer and the irregularities in horizontal distribution are presumptively greatest at that time. During the winter the extended layers of clouds give us no *a priori* reason to expect large irregularities in the geographical distribution of snow fall and rain. Hellmann's records show that the geographical irregularities in the catch of his gauges is really least in summer and greatest in winter, thus confirming our convictions that on the average of the year the precipitation is uniformly distributed and the variations in catch depend on the geographical distribution of the wind at the gauges during the fall of rain and snow.

The eleven gauges here selected from Hellmann's data were unprotected and uniformly 1.07 meters above ground, and it is evident that they would not have necessarily shown a similar discrepancy of 6 per cent among themselves had they been placed at some other altitude. As the absolute deficits of each gauge increase like the wind with the square root of the altitude, so also should the apparent irregularities in geographical distribution. But this rule should not be so far stretched as to assume that gauges at the ground surface would therefore show no irregularities in the horizontal distribution of rain, the fact being that there is even for them an outstanding uncertainty of 2 per cent, which is the total combined effect of all the irregularities of measurement and the drifting of snow or rain.

In general, then, we conclude that in the case of a number of gauges placed within a few miles of each other, and of which we know nothing as to the height and exposure, except that in general the observers have placed them in fairly open situations, there is no reason to give a preference to the reports of one gauge rather than that of another, since if the observers are equally reliable the irregularities of catch are likely to far exceed the errors of careful observers. Again, the probable error of 6 per cent, due to unobserved and uncontrollable irregularities in the action of the wind on these ordinary cylindrical gauges located 1.07 meters above the ground, indicates the utmost limit to which any attempt at refinement in drawing annual isohyetal lines should be carried at present, at least in the climates such as that of Berlin, and until the data are corrected for wind effects. Finally, any attempt to deduce from such gauges the relative rainfall over the forest, the cleared land, the hill and the valley, can only be successful in so far as we make due allowance for the influence of the wind and the character of the precipitation.

CHRONOLOGICAL VARIATIONS OF RAINFALL.

What has just been said with regard to geographical distribution holds good equally with regard to the chronological variations in rainfall. Undoubtedly there are years of large and of small precipitation, but if we analyze these years we shall see that they differ, not only in the quantity, but at the same time in the quality of the precipitation and in the forces of the winds. Until we are able to correct the measured rain or snow for the wind effect we must include this large source of uncertainty in the catalogue of errors to which our measurements are subject; thus, in some years, there may be a heavy snowfall of very light snowflakes falling during strong wind, and in spite of all our efforts to estimate we get too small a record. Again, if we confine ourselves to the summer rains only, namely, those that directly affect the growth of plants, we shall find that in almost every long-continued series of observations at any locality trees, houses, and other obstacles have gradually grown up in the neighborhood so that the average wind force at the gauge has undergone a steady progressive diminution and the gauge, therefore, catches a larger percentage at the close of the series than at the beginning, unless the obstacles were always so near as to shelter the gauges. I have computed the departure of each annual total precipitation (rain and snow) from the mean of forty-six years at Fort Leavenworth, Kans. (using post-surgeon's record only); of twenty-two years at Spiceland, Ind. (observations by H. R. Dawson), and forty-two years at Washington, D. C. (observations at the Naval Observatory). From the mean of these departures it is easy to compute the so-called probable error or departure for any one year, or the index of variability of annual precipitation. The results are given in the accompanying Table VIII, and are interpreted in the following paragraph:

TABLE VIII.

Stations.	Number of years.	Average total annual precipitation.	Probable error of annual precipitation.		Probable error of mean of 49 years.	
		Inches.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*
Leavenworth	46	32.48	6.02	18	0.86	2.6
Spiceland	22	39.40	5.47	14	0.78	2.0
Washington	42	39.48	5.20	13	0.74	1.9

The mean annual catch at the Fort Leavenworth gauge is 32.48 inches, as given by 46 years of observations, which, however, differ among themselves from year to year so much that it is an even chance that the catch of any one year will differ from this mean by more or less than 18 per cent of its value or by 6.02 inches; this 18 per cent is in part due to actual irregularities in rainfall and in part to the variable effect of the wind and the irregular proportions of snow and rain; the actual rainfall is larger than this catch by an unknown amount depending on the character of the precipitation and the strength of the wind at the mouth of the gauge.

It is therefore evident that any conclusion as to a change of climate during these years involving quantities less than the probable errors of the mean rainfall must be entirely illusory.

RECOMMENDATIONS.

Our study of the rain gauge (section 6) and its errors would have a melancholy conclusion did it not afford us some suggestion as to the proper methods of determining and allowing for these errors. In view of our present knowledge we now see that in establishing new stations better methods of exposure should be adopted and such as are in fact very different from those that have hitherto been considered allowable. We must closely imitate the conditions prevailing at the average surface of the ground; that is to say, in the order of preference the exposure would be: (1) the pit gauge; (2) the protected or the shielded gauge near the ground; (3) several protected or shielded gauges distributed over a flat roof; (4) the shielded gauge on posts considerably elevated above slanting roofs. Moreover, in no case should a single gauge be relied upon, but in all cases at least two similar gauges at very different heights should be observed. From the records of these two gauges we can compute the catch of the normal pit gauge by the formula previously given.

As this formula is also applicable to the ordinary and, in fact, any form of gauge, we furthermore see that an approximate correction, needed to reduce valuable past records to the normal gauge, may now be determined, if these old gauges are still being recorded, by at once establishing near them two or more similar gauges at considerably different heights; from the records of all these gauges for the next few years we may determine, at least approximately, a correction applicable to the past years of historical records. Finally, we are warned against attempting to draw from past records conclusions that are finer than the data will justify.

APPLICATION TO FORESTRY.

To this presentation of the rain-gauge question I will add that although the ideas here given may not be altogether new to those especially interested in rainfall, yet their application to the special precaution of establishing rain gauges in pairs at two different altitudes has only been carried out by Ebermayer in Bavaria, and more recently by Brandis and Blanford in the forests of the central provinces of India, but

I do not know that the formula for correction has as yet been used by them. Blanford placed his upper gauges at the height of 60 feet, *i. e.*, above the tree tops, and the lower ones at 1 foot. The result of his first year's observations showed that the high gauges in the forests gave 4 per cent more rain than the high ones in the open fields, a result entirely in accordance with the facts and views we have already presented; the gauges in the forests were at a height above the average tops of the foliage of the trees, decidedly less than the 90 feet by which the gauges in the open lands were elevated above the ground, therefore the high forest gauges should experience less wind and consequently catch more rain than the high open land gauges, while the average rainfall for the whole country averages the same. Again, Blanford's low gauge gave 2 per cent greater catch in the forest than in the open land, a result also perfectly accordant with our views (Met. Zeit., 1888, v, p. 236) and serving to dissipate the last argument in favor of the idea that forests appreciably increase the rainfall as distinguished from the catch of the gauge.

The preceding study assumes that of the local pairs of gauges one at least is high enough to escape spattering from the ground, and this is easily attained in ordinary rains, but in the case of drifting snow this is difficult, and I will present my conclusions as to the correction for drift and spatter at some future time.

Appendix 2.

ANALYSIS OF THE CAUSES OF RAINFALL WITH SPECIAL RELATION TO SURFACE CONDITIONS.

By George E. Curtis.

The possibility of changing the amount of rainfall by human agency has in late years received a great deal of popular attention, and an undercurrent of hypothesis with regard to it has gradually set in, which itself has stimulated scientific inquiry. The question has been directed most frequently to the effect of forests and to the special inquiry as to whether forestation increases and deforestation decreases the rainfall.

In this inquiry the statistical method has been extensively employed, and all the existing rainfall data bearing upon the question and some that are entirely irrelevant have been discussed. Special rainfall observations have also been inaugurated for the purpose of determining the relation of forests to rainfall. Without giving a résumé of these various investigations it is sufficient to state that no definitive conclusion has as yet been derived from them. The one conclusion which the statistical results seem to yield is that if forests affect the rainfall the amount of effect has in most cases not been greater than the amount of probable error in the observations themselves, and therefore the statistics give no assurance that the effect is not an error of observation. This, however, is a result of importance, for it serves to delimit, for the regions to which the statistics apply, a maximum value which the supposed effect of forests has not exceeded. This maximum value is in most cases but a small fraction of the total rainfall, an amount too small to be of any considerable hydrographic or economic importance. Another reason for the unsatisfactory results of the statistical investigations is that they have seldom been combined with a rational explanation of the process by which a change in the rainfall may be brought about, and, consequently, they have not helped to clarify the misty meteorological conceptions which are current thereon. To do this is the object of this paper.

If in any region the rainfall is increased by a forest cover it must be brought about either (1) by an increase in evaporation, which increase must be precipitated over the same region, or (2) by a diversion to the forest area of rain that would otherwise fall in some other locality.

Let us now analyze the causes and conditions of rainfall, so far as they are now understood, and see if the results will not materially aid us in determining how far and in what cases each of these methods of increasing the rainfall can be operative and efficient. I say in what cases, for one of the most important objects of this analysis will be to make clear that an effect that obtains in one climate may be entirely absent in another. Ideas as to the causes of rain have been greatly simplified by recent studies, and many different conditions that are generally enumerated by the books as productive of rain have been set aside.

The following quotation from a recent paper by Blanford sets forth with great clearness the opinions that meteorologists are now adopting:

"As a result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain slopes, etc., are either inoperative or relatively insignificant." (Nature, XXXIX, 583.)

The ascensional movement of the air requisite to dynamic cooling may be brought about by three different processes: (1) by convective currents; (2) by hills and mountains; (3) by cyclonic circulation; and I classify rainfall as convective, orographic, or cyclonic, according as it is due to the first, second, or third of these causes of ascensional movement. Of course in some cases all of these may be operative at the same time, but for the purposes of analysis they will be separately considered.

In a region of purely *convective* rainfall, the circulation is primarily vertical, and the moisture evaporated is largely precipitated before being carried away by horizontal currents. Therefore an increased evaporation will be followed by an increased rainfall. Consequently any change in surface condition which increases or diminishes the evaporation will, in such a climate, be followed by a corresponding increase or decrease in precipitation.

In the case of *orographic* rainfall, currents that are essentially horizontal are forced to become locally ascending. The moisture evaporated in the region lying in the path of the current is partially or entirely precipitated over the region where the ascensional movement is developed. Consequently an increased evaporation will, to a greater or less extent, be restored to the basin by an increased precipitation. The extent to which this will take place, that is, the proportion of the increase of moisture that will be returned to the basin, will depend on the extent and height of the mountains and the relative frequency of the orographic rain-bearing winds. For example, if these winds prevail only half of the time, only half of an increased evaporation can, in general, be precipitated as orographic rainfall. It seems quite possible, therefore, with observations showing the amount of change in the evaporation and with observations of the relative frequency of wind direction, to compute with considerable closeness a maximum value which the resulting change in rainfall can not exceed.

The second point to be considered with respect to orographic rainfall is whether a forested hill or mountain can originate or divert to itself moisture-laden currents which, without a forest cover, would not exist or would give their rain to other localities. Mountains, by means of their heated surfaces, develop upward currents, but when they are forest covered the observations presented by Mr. Fernow in this bulletin show that the air is less heated than when the surface is bare. Forests will, therefore, tend to diminish rather than to augment the diurnal currents which set in upward toward the summit, and which, by dynamic cooling, precipitate their moisture. Likewise, there is lacking any sufficient reason to suppose that lateral currents moving in some other direction will more likely be deflected from their course and diverted toward this mountain summit because it is covered with forest and hence relatively cool.

The general class called *cyclonic* rainfall includes a great variety of rain types related to a cyclonic circulation, some of which are as yet by no means well understood.

In the ordinary progressive area of low pressure the cyclonic circulation is largely horizontal, but with an upward component. This upward component produces the usual rainfall of our cyclonic storms. In these storms the horizontal component of the circulation is so large that the moisture evaporated over one region is precipitated over another. Consequently in regions where rainfall is of this type, an increased evaporation in any region will not be followed by an increased rainfall in that same locality.

In local thunder storms we have a type of rain related to a cyclonic circulation in which the vertical component often becomes very large, as compared with the horizontal component. This predominating vertical component is due to convection and the accompanying rainfall is to be considered as partly or largely convective. Convection induces and initiates a cyclonic circulation which may continue after the direct convective action has ceased. It becomes desirable, therefore, to separate the directly convective rainfall, whose amount can be locally increased by increase of evaporation, from the cyclonic rainfall whose amount can not be so increased. An approximate separation can be made when the diurnal periodicity of rain is known; for an excess of rainfall during the afternoon hours may be classed as convective.

Secondly, we have to consider the question as to whether cyclonic rainstorms can be deflected from one course to another by difference in surface conditions. Evidently great areas of low pressure can not be affected and so the question is restricted to local cyclonic storms of small area. With respect to these the question is to be answered in the affirmative, for it is entirely in accord with physical principles to suppose that small cyclonic storms, areas of clouds and disturbance and other unsettled masses of air with a progressive motion, will tend to follow paths of high humidity and high temperature, lines of atmospheric weakness which all disturbances will seek, just as seismic disturbances follow lines of weakness in the earth's crust.

Whether the air over a forested area as compared with a neighboring unforested area constitutes such a preferable storm path is a question to which a dogmatic answer can not now be given. As shown by observation the absolute humidity is in general higher over the forest and the temperature lower than over adjacent open spaces. These are apparently conflicting conditions—one decreasing, the other increasing the relative density and stability of the forest air. It seems hardly probable that the resultant will have any quantitative importance. However, the investigation of the question is a fruitful direction of meteorological inquiry.

The practical point here to be emphasized is that it is not enough to say that the air over a forest is more humid and that therefore there will probably be more rainfall. The increased humidity will be quite ineffective unless this moist air can be cooled dynamically over the region itself, and thus condensed and precipitated. This is a necessary additional condition, and the evidence that this will occur in any relative high degree, either by convection currents or by deflected storm paths is yet lacking.

CLIMATIC ILLUSTRATIONS.

The equatorial rain belt is the most prominent region with almost exclusively convective rainfall. The Brazilian forest region, the Aruwhimi district of central Africa, the Malaysian Archipelago, and the valley of Upper Assam in India are in or near this belt. They have light winds, and the moisture evaporated from the surface is precipitated before being carried to any considerable distance by horizontal currents. Under these conditions an increase or decrease in the evaporation will be followed by an increase or decrease in rainfall. But they are the very regions where any material change in the evaporation appears to be most difficult to effect.

The evaporation is large. Blanford estimated that for the Aruwhimi district probably over half of the rainfall is due to the direct restoration of the moisture evaporated. The surface is maintained in a continual state of saturation and evaporation proceeds uninterruptedly at a nearly uniform rate. How will deforestation affect this evaporation? In the first place, a cleared surface will have a higher temperature, and the winds will have freer play, both of which results will conduce to increase the evaporation, and, consequently, also to increase the rainfall. The wind effect, however, will be small because the regions under consideration are in the belt of calms. On the other hand, if deforestation should initially induce a materially increased run-off, so that there should be left much less water to evaporate, the evaporation would be diminished, and consequently also the rainfall would be diminished; and when the rainfall had fallen off the streams would fall to their previous quantity of discharge. We have, therefore, a possibility of two opposite tendencies acting at the same time—one to increase the rainfall, the other to decrease it. The question as to which will preponderate, and to what extent, is apparently a question to be ascertained for each separate district, for the result in one region may be quite different from what it will be in another. Furthermore, this analysis suggests that a very promising method of investigating the effect of forestation and deforestation in districts of convective rainfall appears to be not by observations of rainfall, but by comparative observations of the discharge of the streams. Finally, in the equatorial belt, which is the only portion of the world having an almost exclusively vertical circulation, the rainfall is so much in excess of the needs of vegetation that its possible modification has not the same economic importance as in higher latitudes. There is no motive to increase it, and if diminished no detriment would result.

Bordering on each side of the equatorial belt are the regions of the trades, which, over the ocean, are almost rainless; but over intercepting land areas, such as Central America and the Antilles, considerable rainfall occurs. This is frequently difficult to analyze, but it is largely convective and in hilly regions partly orographic. The seasonal distribution shows that the rainfall is intimately related to the annual oscillation of the limits of the trade wind, and that the rainy season requires a special explanation. With the exception of the well-known tropical cyclones of the seas, the distribution of pressure over the trade region is unfavorable to the development of a cyclonic circulation, and consequently cyclonic rainfall is seldom presented. It is easily seen that the application of this very general statement to the question of the effect of surface conditions requires us to consider some special individual locality. Let us take the island of Barbados. This island is 21 miles long, 14 miles across its widest part, and lies in latitude 13° N., longitude 59° 37′ W. Its interior is hilly and rises at points to over a thousand feet in height. From an extended series of rainfall records carried on by Governor Rawson the average rainfall on the coast is found to be 50 inches, and rising 64 inches on the windward side and in the central highlands. During three-fourths of the year the northeast trade wind prevails and the rain comes from that quarter. In October, when the southern limit of the trade reaches the island, the wind turns to the west and the heaviest rains occur, making it the wet season. The distribution of rain over the island, both with the trade wind and the west wind, shows that the rainfall is partly orographic, but probably the largest part of it must be considered as convective. On account of the smallness of the island and the prevailing fresh winds, practically all of the moisture thus precipitated on the island comes from the ocean, and the moisture evaporated from the island itself is carried away to sea. When the island was covered with forests the convective action of the island could not have been greater than at present, because its temperature would have been lower, and if a greater evaporation took place there no appreciable amount of the additional vapor could be precipitated on the island itself. We have every reason, therefore, to conclude that destruction of forests or any other surface change in Barbados is powerless to sensibly increase or decrease its rainfall.

Passing from the region of trades, we reach latitudes favorable to cyclonic development. Here convective and cyclonic action are frequently combined. In the warmer latitudes and in the summer season, the equilibrium of the atmosphere becomes unstable and convection currents are set up which induce an incipient cyclonic circulation. Then there is a combined convective and cyclonic rainfall. As we go northward the direct convective feature of the rainfall becomes less prominent, and the purely cyclonic rainfall predominates. Over the whole region orographic rainfall is added to the other two classes when hills or mountains are situated in the path of moisture-laden currents. With this general statement the further examination of the effect of surface conditions on the rainfall in middle latitudes must be applied to concrete cases.

In the United States the Great Plains region of Kansas, Nebraska, and the Dakotas is that for which a variation in rainfall has most often been claimed or anticipated. Many settlers believe that the so-called "rain belt" is moving rapidly westward with the extension of cultivation and settlement.

The single condition favorable to such an increase of rainfall consists in the steadier and larger evaporation which no doubt takes place over the cultivated area, but the other conditions necessary to condense and precipitate this moisture over the same region are largely absent. There are no hills or mountains to produce orographic rainfall, and without these barriers the high winds constantly carry away the moisture evaporated from the surface and precipitate it far to the eastward. Hence, not only is the increased moisture in the air but a small fraction of the total rainfall, but also only a small portion of this is gathered into convective or cyclonic currents and restored again by them to the prairie soil. Evidently a small amount must be thus restored in every summer rain and the total rainfall increased thereby, but quantitatively this must be very small.

There is one region deficient in rainfall and water supply for which claims in behalf of an actual or possible increase of rainfall due to human agency are less often made, but which the preceding analysis leads me to believe would not be unreasonable to anticipate. I refer to the San Joaquin Valley of California. This valley is flanked by the Coast Range on the west and by the Sierras on the east. The moisture evaporated from the surface can not escape from the basin, but will be largely precipitated either over the valley or on the sides of the adjacent mountains which constitute its watershed. If, therefore, the increase in irrigation and in the extent of cultivated area produces a material increase in the evaporation, it seems reasonable to expect that this moisture will be restored by an increased rainfall in the valley and on the adjacent mountain sides. One consideration only would appear to retard and diminish this effect. The inclosure of the valley prevents that rapid indraft of air which renders possible a rapid vertical circulation. Thus the activity of the whole process is rendered sluggish and the total amount of moisture passing through the cycle from evaporation to rainfall is smaller than with a more rapid circulation.

In the manner here outlined the possibility of a variation of rainfall may be investigated for any region, and with sufficient meteorological data even quantitative values may be computed. The general result indicated by the analysis of the physical processes involved as well as by the statistical data so far collected is that the margin of such possible change is very small. In most cases it can not exceed a small per cent, and in other cases it can not occur at all. It appears, therefore that in the estimation of the importance and value of forests a disproportionate and undue amount of emphasis has been popularly given to such an influence.

INDEX.

Abbe, Prof. Cleveland, determination of the true amount of precipitation and its bearing on theories of forest influences, 175.
Air currents, effects of forests on, 18, 120.
Air humidity:
  per cent of, 16.
  in woods, glades, and plains, compared, 102.
  relative, 103.
  Fautrat's observations, 104.
  Liburnau's conclusions, 104.
Air temperatures:
  in interior of forests, 14, 51.
  difference between forests and open fields, 51.
  annual range, 52.
  monthly range, 53.
  deciduous and evergreen forests, 58.
  effect of elevation, 60.
  effect of young forests, 60.
  temperatures in tree crown and above trees, 15, 61.
  temperature gradients, 68.
  Fautrat's observations above trees, 70.
  vegetation, effects on air temperatures, 76.
  effect of evaporation, 81.
  temperatures in glades, forests, and fields, 83.
  Swedish observations, 85.
  conclusions, 88.
Alps, French, effect of denudation, torrents, area needing to be reforested, cost, 159.
Austria, systematic observations in forest meteorology, 33.
Becquerel, M., meteorological observations, 27, 49, 73, 103, 111, 119, 121.
Bohemia observations regarding influences of forests upon precipitation, 126.
Brazil, observations regarding influences of forests upon precipitation, 128.
Carbon, annual production by plants, heat absorbed by assimilation of carbon, 82.
Chinook, effect on temperature, 133.
Climate:
  effect of forests on, 9, 17, 23, 24.
  general and local, 10.
  literature of forest influence on, methods of determining such influence, imperfect instruments and observations, 25.
  no certainty that a given change of climate is due to change in forest conditions, 26.
  secular changes, 26.
  Dr. Liburnau's conclusions, 34.
  (*See also* Meteorology and Water supply.)
Climatic illustrations, 189.
Climatology, forest, two problems, 23.
  methods of investigation, 25.
Curtis, George E., analysis of the causes of rainfall, with special relation to surface conditions, 187.
Currents, air. (*See* Air currents.)
Congress:
  of German foresters and farmers at Vienna, 1868, 35.
  international meteorological, at Vienna, 1880, 36.
Denudation, effect in French Alps, 159.
Drainage:
  influence of forests upon, 20, 141, 157.
  retardation of waterflow by forests, 158.
  experience in the French Alps, 159.
  examples of the influence of forests on waterflow, 162.
  (*See also* Water supply.)
Ebermayer, Dr., meteorological observations, 30, 75, 99, 146, 148, 150, 171.
Evaporation:
  per cent in field and forest, 16.
  influence of forests upon, 20, 96, 132.
  annual, in fields and woods compared with precipitation, 96, 100, 134.
  influenced by wind, 133.
  reduced by forests, 138.
  modified by trees of different kinds and ages, 98.
  amount from bare soil and water surface, 99.
  effect of litter on, 99.
Fautrat, M., observations, meteorological, 29, 69, 103, 108, 125.
Fernow, B. E.:
  article—introduction and summary of conclusions, 9.
  relation of forests to water supplies, 123.
  notes on the sanitary significance of forests, 171.
Filtration:
  process, 139.
  Wollny's experiments, 148.
  relation to floods, 150.
  influence of various soils upon, 150.
  influence of grass cover, 150.
  influence of snow, 152.
  influence of the forest floor, 152.
Forest influences. (*See also* Meteorology, forest.)
  influence upon climate and waterflow, 9.
  reasoning from insufficient premises, need of further exact observations, 10.
  water management dependent upon forest management, 12.
  summary of conclusions, 13.
  difference of meteorological conditions within and without the forests, 14.

- Forest influences—Continued.
  - influence of forests upon climate of the surrounding country, 17.
  - influence upon upper and lower air currents, 18.
  - influence upon comparative temperature in forests and open fields, 18.
  - phenomena of glades inclosed by forests, 19.
  - influences on water and soil conditions, 20.
  - sanitary influence, 21, 171.
  - forests a special kind of surface covering, 23.
  - methods of investigation, 25.
  - systematic meteorological observations, 26.
  - French, 27.
  - German, 30, 39.
  - Swedish, 31.
  - Austrian, 33.
  - effects on temperature of soil, 40–50.
  - comparison of effect of deciduous and evergreen trees, 47.
  - temperatures of air in forests, 51–69.
  - temperatures above forests, 69–72.
  - tree temperatures, 72–76.
  - relation of forests to evaporation, 96–102.
  - relation to humidity, 102–105.
  - rainfall in, above, and near forests, 106–118.
  - windbreak, effect of, 118.
  - relation to water supplies, 123–170.
  - influence on hailstorms, 129.
  - influence on surface drainage, 20, 157.
  - sanitary significance of, 21, 171.
  - relation of forest soil to cholera, typhus, yellow fever, and malaria—investigations in India, 172.
  - value of city parks, 173.
  - influence on wind and storms, 118.
  - influence on evaporation, 138.
  - effect on rainfall, 175.
- France:
  - observations of Becquerel on meteorological problems, 27, 49, 73, 103, 111, 119, 121.
  - observations of Krutzsch and Rivoli, 28.
  - government investigations of forest influences on climate, 29.
  - Fautrat's observations above and below tree tops, 29.
  - observations near Nancy on rainfall, 126.
- Frost, effects of vegetation upon, 76.
- Gauges, rain:
  - relation of pattern and altitude to accuracy of measurements, 176.
  - why elevated gauges catch less rain than those near the ground, 176.
  - action of wind upon, 177.
  - observations of Mordecai and Börnstein, 178.
  - observations of Wild and others, 179.
  - elimination of errors, 180.
- Glades:
  - in forests, special phenomena of, 19.
  - temperatures in, 19, 83.
- Geneva, observations on tree temperatures at, 72.
- Germany:
  - results of Dr. Ebermayer's observations on interior forest climate, 30.
  - meteorological observation stations, 14.
  - instruments used, 39.
- Germany—Continued.
  - observations on soil temperatures, 40.
  - observations on temperatures in interior of forests, 51.
  - temperature in tree crowns and above forests, 61.
  - relation of evaporation to forests, 96, 134.
  - observations on precipitation, 107, 113, 134.
  - water capacity of soils and soil covers, 146.
  - water conductivity of soils, 149.
- Gradients, temperature, 68.
- Hailstorms, supposed influence of forests upon, 121, 129.
- Hamberg, Dr., observations on temperature in woods, glades, and plains, 85.
- Harrington, M. W., review of forest meteorological observations: a study preliminary to the discussion of the relations of forests to climate, 23–121.
- Heat:
  - Hamberg's observations on temperature and humidity, 31, 85.
  - complicated relation to vegetation, 76.
  - amount absorbed in transpiration of plants, 80.
  - degree necessary to produce evaporation in water, 81.
  - amount absorbed by forests, 81.
  - amount produced by vertical sun's rays, 82.
  - percentage of heat of vertical sun's rays absorbed in passing through the air, 82.
  - absorption by assimilation of carbon, 82.
  - variations in degrees during the day and at night, 83.
  - degrees in forests and fields, (Sweden,) 85.
  - (*See also* Temperatures.)
- Höhnel, investigations on transpiration of forests, 78.
- Hough, F. B., report on forest climate, 30.
- Humidity, forests and, 16, 102.
- India:
  - temperatures in wooded and treeless territories of, 91.
  - influence of forests upon precipitation, 128.
  - sanitary influence of forests, 172.
- Influence of forests. (*See* Forests.)
- Interception. (*See* Water supply.)
- Leaves: time of appearance and disappearance in deciduous trees, effect on temperature in spring and summer, 60.
- Liburnau, Dr. Lorenz, meteorological observations, 33, 71, 104.
- Light, influence on transpiration, 77.
- Litter effects:
  - on soil temperature, 49.
  - on water capacity, 147.
  - on conductivity of soils, 150.
  - on drainage, 152.
  - malaria, cholera, etc., relation of forests to, 172.
- Meteorological conference, international, Vienna, 36.
- Meteorology, forest:
  - difference of meteorological conditions within and without the forest, 14.
  - influence of forests upon the climate of the surrounding country, 17.

Meteorology, forest—Continued.
- influence upon water and soil conditions, 20.
- sanitary influence of forests, 21.
- systematic observations on, 26.
- literature of forest meteorology, 24.
- methods of solving problems of, 25.
- early observations on—Hunter, Schaepff, 26; Pictet and Maurice, 26; Kaemtz, Bravais, and Thomas, Borgeau, 27.
- later observations, France, Messrs. Becquerel, 27; Contegril, Bellot, 28; Germany, Hofman, Baur, Krutzsch, Rivoli, 28.
- observations of Mathieu, at Nancy, and of Fautrat and Sartiaux, 29.
- observations of Ebermayer in Bavaria, 30.
- German stations for observations, description of, 30.
- observations in Sweden, 31.
- in Austria, description of stations, Dr. Lorenz-Liburnau, 33.
- results of observations, 33.
- conclusions of Dr. Liburnau as to influence of forests upon climate, 34.
- programme of observations proposed by congress of German foresters and farmers, 35.
- system of Prussian service, 35.
- conference at Vienna, 36.
- objects and methods, parallel stations, 37.
- Piche's evaporometer, 38.
- instruments and methods of the German service, 39.
- Dr. Liburnau's method, 39.
- soil temperatures, 40.
- mean annual differences of temperature for fields and woods at the surface and depths of 6 inches and 4 feet, 41.
- effects of forest litter, 43, 49.
- differences in the influence of deciduous and of evergreen trees upon soil temperature, 46.
- effect of elevation above sea level, 48.
- differences in young trees and old, 48.
- differences of soil temperature under sod and bare surface, 50.
- temperatures of soil inside and outside of a forest, 50.
- air temperatures in forests and open fields, 51.
- annual range, 51.
- monthly range, 53.
- difference in the influence of deciduous and of evergreen forests, 58.
- effect of elevation above sea level, 60.
- effect of young forests, 60.
- temperatures in the tree crown and above trees, 61.
- temperature gradients, 68.
- temperature above forests, 69.
- Fautrat's observation, 70.
- tree temperature, 72.
- Geneva observations, 73.
- tree trunk a poor conductor of heat, 74.
- differences between tree and air temperatures, 74.
- vegetation and air temperatures, 76.
- heat used in processes of vegetation, 76.
- transpiration, 77.

Meteorology, forest—Continued.
- Höhnel's investigations, 78.
- theoretical calculation of heat absorption, 80.
- temperatures in woods, glades, and plains, 83.
- Swedish observations, 84.
- conclusions regarding temperatures within and without forests, 88.
- temperatures in wooded and treeless territories, 89.
- Woelkoff's observations, 91.
- temperatures in relation to parallels of latitude, 92.
- relation of evaporation to forests, 96, 132.
- annual evaporation in fields and woods compared with precipitation, 96, 100, 134.
- percentage of evaporatien in woods compared with that in open fields, 97, 99, 132, 138.
- evaporation as modified by trees of different kinds or different ages, 98.
- evaporation from bare soil and from water surface, 99.
- effect of litter on evaporation, 99.
- forests and humidity, 102.
- absolute humidity in woods, glades, and plains compared, 102.
- relative humidity, 103.
- Fautrat's observations, 104.
- Dr. Liburnau's conclusions, 104.
- carbonic-acid gas and ozone taken up by forests, 105.
- rainfall in, above, and near forests, 106.
- rain caught under trees and in the open fields, 106.
- difference in case of evergreen and deciduous trees, 107.
- Fautrat's observations, precipitation over woods and open fields, 109, 125.
- German observations, 110.
- influence of forests on rainfall, 111-118.
- French observations, 112.
- precipitation over wooded and treeless districts, 113, 126.
- influence of altitudes, 127.
- Java and Celebes, 115.
- the Amazon, 129.
- observations in India, 91, 117, 128.
- presumption in favor of forests, 117, 125.
- wind and storms, 118.
- windbreak effect of forests, 118, 133.
- forest circulation, 120.
- influence on fogs, frost, and ice, on hailstorms, 121, 129.
- water supply, fixed and circulating, 123.
- distribution of circulating, how influenced, 124, 130.
- relation of forests to water supply, 123.
- elements of dissipation, interception, 130.
- evaporation, 132.
- evaporation and precipitation compared, 134.
- transpiration, 136.
- relation of forests to snow, 137.
- conservative and dissipative influences of forests on water supply, 140.
- distribution of terrestrial waters, superficial and underground drainage, brooks and rivers, 141.

Meteorology, forest—Continued.
  run-off, influenced by topography, 143.
  water capacity of soils, 144.
  of litters, 147.
  water conductivity of soils, filtration, 148.
  influence of grass cover upon filtration, 150.
  of other covers, 151.
  of snow, roots of trees, 152.
  of geological stratification, formation of springs, conditions affecting their flow, 153.
  influence of forests upon surface drainage, 157.
  retardation of water flow, 158.
  French Alps experience, 159.
  Mississippi bad lands, 159.
  influence of forests on water flow, examples of, 162.
  effect of removal of forests in the Adirondac region, 165.
  in the basin of the Schuylkill, 166.
  in New Hampshire, 167.
  in other States, 168.
Moisture, quantity of:
  returned into the atmosphere from a forest by transpiration and evaporation from trees and soil, 16. (*See* Humidity.)
Müttrich, Dr., influence of growing forests upon rainfall, 113.
Nancy, France, results of observations on influence of forests upon precipitation, 108, 112, 126.
Observations on forest meteorology: France, 27, 108, 111, 126; Germany, 30, 40, 51, 61, 96, 107, 113, 134, 146, 149; Sweden, 31; Austria, 33.
Parks, city, value of, 173.
Plains, temperature in, 83.
Precipitation:
  over wooded and treeless districts, 111.
  Dr. Lorey's table, 113.
  influence of forests upon, 125.
  results of observations in Bohemia, 126.
  results of observations near Nancy, France, 126.
  results of observations in India and Brazil, 128.
  supposed influence of forests upon hailstorms, 121, 129.
  determination of the true amount of precipitation and its bearing on theories of forest influences, 175.
Rain, not the most satisfactory form of water available for human use, 12.
Rainfall:
  in, above, and near forests, 106.
  Becquerel's observations, 111.
  measurements, relations of pattern and altitude of gauge to accuracy of, 176.
  variations in geographical distribution of, 182.
  chronological variations of, 184.
  analysis of the causes of, with special relation to surface conditions, 187.
Rain-gauge:
  elimination of errors of the, 180.
  instrumental methods, 180.
  observational methods, 181.
Sanitary influence of forests:
  in production of oxygen and ozone, 21.
Sanitary influence of forests—Continued.
  by protection against sun and wind, 21.
  by unfavorable effect upon microbes, 21.
  notes on, 171.
Snow:
  influence of forests on melting of, 20, 152.
  influence on climate and weather, 23.
  influence on percolation and drainage, 152.
Soil conditions, influence of forests upon, 20, 40.
Soil temperatures, 14, 40.
  differences of, 87. (*See* Temperature.)
Springs, their formation and conditions affecting their flow, 153.
Storms, forests, wind, and, 118.
Summary of conclusions as to forest influences, 13.
Sweden:
  results of observations on forest meteorology by Dr. H. E. Hamberg, 31, 84.
Temperatures, air:
  under, within, and above tree crowns, 14, 61.
  in woods, glades, and plains, 15, 83.
  in neighboring forest and open field stations, 19, 51.
  monthly range, German observations, 53.
  in deciduous and evergreen forests, 58.
  in tree crowns and above trees compared with open fields, 61.
  gradients, 68.
  above forests and near ground, difference between evergreen and deciduous trees, 70.
  differences between tree and air, 74.
  relation to transpiration, 76.
  theoretical calculation of heat absorption, 80.
  conclusions regarding temperatures within and without forests, 88.
  temperatures in wooded and treeless territories, 89.
  Dr. Woeikoff's conclusions, 91.
  temperatures near parallels of latitude, 92.
Temperatures, soil:
  in forests and open fields, 40.
  mean annual differences, tables of, 41, 44, 45.
  comparison of effect of evergreen and deciduous trees on, 47.
  influence of elevation, 48.
  effects of litter, 43, 49.
  difference under sod and bare surface, 50.
  differences inside and outside of a forest, 50.
  temperatures, tree, Geneva observations, 72.
Torrents in the French Alps, 159.
Transpiration:
  moisture returned to atmosphere by, 16, 19.
  its relation to temperature, 76.
  to evaporation, 77.
  influence of light on, 77.
  amount of, with different plants, 78.
  amount transpired by evergreen and deciduous trees and various species compared, 79.
  variation from day to day and with the seasons, 80.
  heat absorbed in, 81.
  amount of water in trees, 136.
Trees:
  temperature in the tree crown and above trees, 61.

Trees—Continued.
  temperature of Geneva observations, 72.
  difference of temperature between trees and air, 74.
  (*See also* Temperature, Transpiration, and Evaporation.)
  condensers of aqueous vapor, dew, and hoar frost, 121, 124.
  interception of rainfall by, 130.
  amount of water in, 136.
Vegetation:
  relation to and effects on heat and water, 76.
  amount of heat and water absorbed by, 76.
  effects of absorption on climate, 76, 77, 78.
  effects on air temperature, 76.
  table showing estimated amount of transpiration, evaporation, and precipitation of various plants, 78.
  theoretical calculation of heat absorbed by, 80.
Vines, Dr., table showing effects of sunlight on transpiration of plants, 77.
Water:
  amount caught by rain gauges, 17.
  evaporation affecting air temperatures, 81.
Waters, terrestrial, distribution of, 141.
Water conditions, influence of forests upon, 20.
Water capacity and conductivity of soils and soil-covers, 140, 144.
Water flow, influence of forests upon, examples, 158.
Water management, its connection with forest management, 12.
Water supply:
  the total, 123.
  influence of forests upon the disposition of, 130.
  interception, 130.
  evaporation, 132.
  transpiration, 136.
  elements of conservation, 137.
  effects of forest in the case of snow, 137.
  general effect of forests in reducing evaporation, 138.
  summation of the conservative and dissipative influences, 140.
  formation of springs and conditions affecting their flow, 153.
  (*See also* Evaporation, Rainfall, etc.)
Weather Bureau, memorial of the A. A. A. S. to the Secretary of Agriculture in regard to, 11.
Weather, clear and cloudy, effects on temperature in glades and plains, 87.
Wind and storms, protection afforded by forests, 118.
Windbreaks, effects of, upon crops, 118, 134.
Woeikoff, Dr.:
  on influence of snow-covering on climate, 23.
  temperature, in wooded and treeless territories, 91.
  on parallels of latitude, 92.
  influence of forests on rainfalls, 115.
Wood, as a conductor of heat, 74.
Woods, temperatures in, 83.
  (*See also* Temperature.)
Wooded districts, precipitation in, 111.
Wooded territories, temperatures in, 87.

O

W. V. Mulford
189

U. S. DEPARTMENT OF AGRICULTURE

Walter Mulford

FARMERS' BULLETIN No. 20.

WASHED SOILS:

How to Prevent and Reclaim Them.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1894.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of the Assistant Secretary,
Washington, D. C., October 27, 1894.

Sir: In accordance with your direction I have the honor to transmit herewith for publication a bulletin upon "Washed soils: How to prevent and reclaim them," prepared under my direction, by the Divisions of Chemistry, Soils, Forestry, and Botany, for one of the series of Farmers' Bulletins of this Department.

Thousands of acres of land in this country are abandoned every year because the surface has been washed and gullied beyond the possibility of profitable cultivation. It is believed that the present bulletin, and the simple facts therein presented as to how this erosion, or washing, may be prevented, and how washed and abandoned lands may be reclaimed, will serve a useful purpose in the hands of those farmers who have these trying problems to contend with.

Very respectfully,

Chas. W. Dabney, Jr.,
Assistant Secretary.

Hon. J. Sterling Morton,
Secretary of Agriculture.

CONTENTS.

Page.

The erosion, or washing, of agricultural lands 7

Chemical relations of the soil to surface washing 9

  Organic matter and humus diminish erosion 9

  Lime renders a soil less liable to wash 10

Washing of lands may be prevented by methods of cultivation and underdrainage 11

  Deep plowing diminishes surface washing 11

  The soils should be kept covered with vegetation 11

  Tile drains diminish surface washing 11

  Side-hill ditches 12

  Terracing 13

Recovering gullied hillsides by reforestation 14

  The different ways in which a forest covering protects the soil from washing 14

Recovery of washed soils 15

  Amount of this work being done in France 15

  Where forests should always be maintained 15

Preparation for planting forests 16

  Cultivation is advisable where possible 16

  Use of brush dams to protect young trees 16

  Methods of constructing brush dams in France 16

Planting 17

  Advisability of sowing tree seeds in stubble 17

  Best varieties of trees to be used 18

  How the tree seeds should be gathered and preserved 18

  Planting of seedlings or cuttings 18

  Propagation of trees by layering 20

Grasses and similar vegetation prevent washing and erosion of agricultural lands 20

  Effect of turf in preventing erosion 20

  Varieties of grasses adapted to this work 21

WASHED SOILS: HOW TO PREVENT AND RECLAIM THEM.

THE EROSION, OR WASHING, OF AGRICULTURAL SOILS.

The denudation, or washing, of lands of the higher levels of the earth's surface is a process which no human precaution can wholly prevent. It has been one of the most important forces and factors in the geological changes which have so modified the surface of the earth. The present surface of the largest portion of the United States is made up of this "sedimentary" or "drift" material which has been moved from the place where it was formed through the disintegration and decay of the old crystalline rocks, by water, wind, or moving ice, and which has accumulated to a depth of hundreds or thousands of feet over nearly the entire surface of the country. It is estimated that the general surface of the land in the area of the crystalline rocks of the Piedmont Plateau has been lowered at least 2,000 feet by this continual washing. This vast amount of material has been slowly removed and deposited elsewhere by the very same agents which we are contending with to-day in our gullied fields; for this denudation, or erosion, is still going on, as it has been for ages past.

As a rule this denudation is exceedingly slow and the general level of large tracts of country is not lowered more than an inch or two in a hundred years. Where the change is as slow as this it is undoubtedly of benefit to the human race, as in the course of time it must carry off the soil which has been used over and over again for vegetation and expose fresh material to the roots of plants. With this slow change the natural forces are amply sufficient for the decay of the subsoil and for the conversion of this freshly exposed material into a good soil. When the rate of denudation is excessive, however, and more rapid than the natural decay of the subsoil material which is exposed, it may work serious injury to agricultural lands.

Along the banks of the Ohio River and in very many portions of the South hundreds of fields that were once covered with sturdy forests of oak, maple, walnut, and pine, and which bore under cultivation, after being cleared of the natural growth, large crops of wheat, maize, tobacco, and cotton, may now be seen furrowed with gullies as with the wrinkles of age, and abandoned to brush and briers.

A surface layer of good agricultural soil 6 inches deep resulting from the slow and gradual disintegration and decay of rocks and accumulation of humus may have required hundreds of years for its natural formation, and yet it is liable to be washed away in a single storm.

This excessive erosion, or washing, of lands may be prevented, and the already gullied fields may be recovered, and steep slopes of loose material may be held and prevented from washing—

(*1*) *By chemical means*, in the application of manures and fertilizers and in the accumulation of organic matter, which change the texture of the soil and make it more porous and more absorbent of water, so that there is less to run off over the surface.

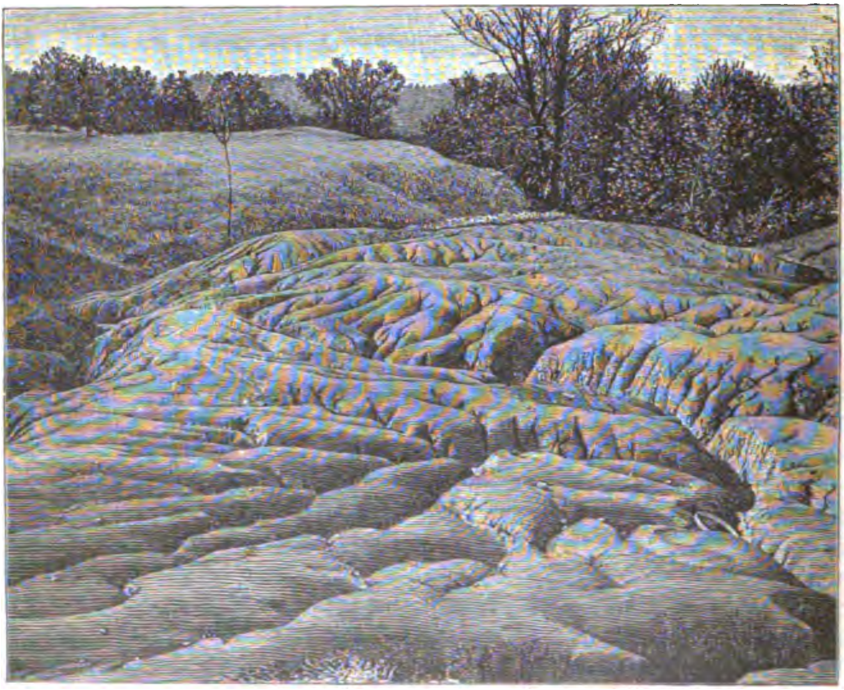


FIG. 1.—An eroded field in the South.

(*2*) *By means of cultivation and underdrainage*, which prevent erosion by distributing the surface flow over the ground and increase the amount carried off by underdrainage.

(*3*) *By reforestation*, or the planting of trees, which act mechanically to prevent washing.

(*4*) *By grass and similar vegetation*, which bind the soil grains and prevent their washing away.

The erosion of a soil is caused by the wearing of the rain and snow waters which can not penetrate into the soil fast enough to be carried away by underdrainage, and which, by reason of the slope or contour of the land, run off over the surface, carrying along particles of sand

and clay. When this water accumulates in a depression in the field the force of the torrent may be sufficient to cut out a great gully in a short space of time.

The extent of washing to which the soil is exposed depends upon the quantity of rainfall in a given time, the slope or contour of the surface, the texture of the soil, the vegetative covering of the surface, and the kind and condition of cultivation. A soil composed chiefly of moderately coarse grains of sand, and having good underdrainage, will absorb the heaviest rainfall without much danger of surface erosion.

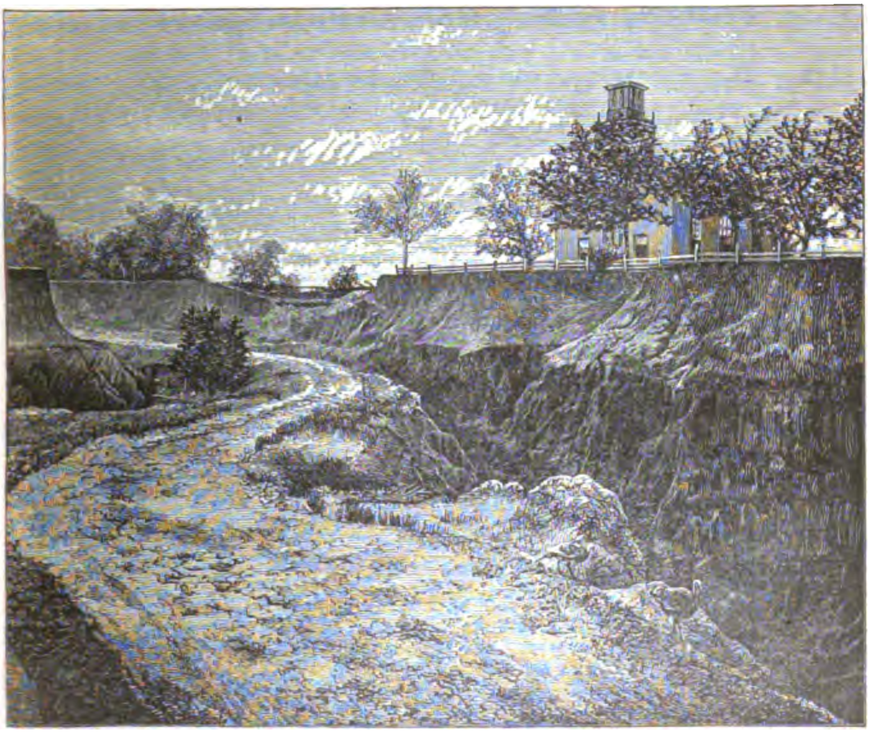


FIG. 2.—Another effect of erosion.

A clay soil, on the other hand, into which the water can not percolate with anything like the rapidity of the precipitation, will be washed and gullied by the torrent of water which must flow over the surface.

CHEMICAL RELATIONS OF THE SOIL TO SURFACE WASHING.

It has been repeatedly shown by experiments and by the experiences of farmers that a soil, as a rule, absorbs water more readily as the content of organic matter and of humus increases. Surface erosion can, therefore, be largely prevented by such a system of cultivation and cropping as will introduce as large a quantity of organic matter into the soil as possible. A very old method of recovering washed and gullied lands is to place straw in the furrows while plowing, the straw not only acting mechanically to hold the soil in place and prevent surface erosion, but also in a very efficient way to increase the quantity of humus, thus making the soil hold large quantities of water which otherwise would have passed off over the surface. In this simple way fields which have been badly washed and gullied and entirely abandoned may be recovered and made highly productive.

The most important thing in the recovery of waste fields is the incorporation of organic matter of some kind in the soil; pea vines, stubble, briers, or leaves from the forest may be used as a source of the organic matter. The straw from one acre of land which has been recovered, as mentioned above, will be sufficient to start the recovery of another acre, even if this be deeply furrowed with gullies. Where enough organic matter can be used as a surface dressing, this layer helps greatly to retain water and to make the underlying soil more absorbent.

As soon as a sufficient supply of humus has been accumulated and the lands are brought up to an adequate condition of fertility, clover or grass should be seeded, if the land is at all suited to these crops, or rye, oats, or field peas should be sown to help hold the surface. Little by little, but more rapidly than would be expected from the forbidding aspect of the field, the land can be reclaimed again and made productive through the accumulation of humus and organic matter. A soil containing a fair quantity of humus will wash less readily than one nearly destitute of this matter.

A soil containing a fair supply of lime is much less liable to wash than one similarly situated and exposed which is deficient in lime. The reason of this is that clays which are deficient in lime, when once brought into suspension by moving waters, will remain in suspension and keep the water turbid for a long time. Clays which are heavily impregnated with lime salts, on the other hand, are in a flocculated state, the fine grains of clay being held together and in contact with the larger grains of sand. This flocculated mass quickly settles and is originally not so easily disturbed and carried off by moving water. A field treated with an abundance of lime is thus less easily washed by heavy rains. The results of investigations by Schulze, Schloesing, and Hilgard have shown in a most emphatic way the beneficial changes which take place, especially in stiff clay soils, by the application of lime.

The change in the physical condition of the soil which is produced by the lime, and which is likewise produced by a number of other chemicals ordinarily used in commercial fertilizers, is another important factor worthy of consideration. A stiff clay soil is practically impervious to the penetration of surface water when it is delivered in such torrents as we are liable to have in our summer storms. A well-limed soil, on the contrary, although it may contain as much clay but in which the particles are flocculated or drawn together, is much more pervious to water, and the amount of water which the soil will carry down through underdrainage is increased, and the excess which has to flow off over the surface is diminished. The surface washing of cultivated fields, especially those which are naturally deficient in lime, can be greatly diminished, therefore, by the free application of this substance to them.

A number of the ordinary fertilizing materials have an important effect upon the texture of soils and upon the permeability of soils to water, but few systematic investigations have been carried on in this line and not much, except of local importance, has been definitely settled by experiments or by the experiences of farmers.

WASHING OF LANDS MAY BE PREVENTED BY METHODS OF CULTIVATION AND UNDERDRAINAGE.

The depth and character of the tillage are very important factors in the washing of lands. A field in a condition of fine tilth and plowed to a depth of 10 inches will hold 2 inches of rainfall and absorb it very readily, and a soil in such a condition will suffer no surface washing from any ordinary rainfall. Where it is possible, therefore, land which is apt to wash should have the soil gradually deepened and be kept in a fine state of tilth so as to increase the storage capacity for excessive precipitations. This will not only save the surface from being washed and gullied, but it will also increase the store of moisture held by the soil, which is of very great value in the time of drought.

It is important also for this, as for other reasons, that the soil be covered with vegetation as much as possible throughout the year, as the roots and organic matter serve to bind the grains of the soil together. In some parts of Holland the drifting sands of the coast, which shift their position with every storm, often cover up valuable farming lands. Vast areas of these sands have been reclaimed and made productive by being covered with vegetation, while the roots and remains of organic matter hold the soil grains in place and prevent them from drifting and covering up more valuable lands. Any crop which requires very clean culture, as for example, cotton, is exhausting to the land for the reason that constant exposure of the surface to the sun and storms uses up the organic matter, makes the soil less porous, and the soil particles themselves are more easily washed away; so that, this clean cultivation is in its effects very favorable to excessive erosion. With crops which require such clean cultivation it is very advantageous to sow some crop like rye in the field during the last working of the crop both to bind the surface and protect it from washing in the winter and for other benefits which such a covering provides.

Another very effective method, when properly carried out, to prevent the washing of lands is to underdrain the soil with tile or other drains. These drains carry off quite rapidly an excess of moisture, so that much more of the rainfall is absorbed by the soil and carried off through the drains and less washes over the surface of the land. Not only this, but a well-underdrained field is usually dryer and more porous, and has a greater capacity for absorbing the excessive rainfall and thus preventing surface washing. A field thoroughly underdrained with tile drains will carry off the water of any ordinary rainfall without any surface erosion. This method is very effective, but is likewise very expensive, and can not be used economically in extensive farming solely for this purpose of protecting the land from washing.

While the land may thus be made more porous and more absorbent of water—through the increase of the amount of organic matter or of humus, through the use of lime and other fertilizing material, through the deepening of the soil by gradually increasing the depth of cultivation, by so cropping it that it shall be covered with vegetation as much of the year as possible, and by underdraining the land—still, these methods may not be sufficient to so change the chemical and physical texture of the soil as to enable it to absorb the rain as it falls and to prevent an excess of water washing and eroding the surface where the contour of the land is such as to promote erosion from the surface flow of the excess of water.

It will be necessary in this case to provide for a more uniform distribution of the flow over the surface, and to prevent any accumulation of water which would have the effect of a torrential stream. This is secured in a great measure by laying off the rows according to the contour of the surface, so that each row will have a very slight incline of not more than from 1 to 6 inches in 100 feet, and in which the flow of water would be so slow that there would be little or no erosion. Theoretically, this is a fine idea, to let each row carry off its own proportion of the excess of rainfall so gently that there shall be no erosion, thus acting as a minature drain. Practically, however, it is often impossible to keep these rows from breaking through, and when the bed is once broken and the water overflows into the next row the accumulation of water is sufficient to break down bed after bed until the rows from all the field are discharging into this narrow channel.

To overcome this difficulty sidehill ditches may be used in which larger and more substantial ditches are provided, following very nearly the contour of the field, so that there shall be a fall of from 1 to 6 inches in 100 feet. The distance apart of the ditches will depend upon the slope of the field; with a very steep slope they should be close together, often not over 6 to 10 feet apart; with a gentle slope they should be at intervals of 15 or 20 feet, or even farther apart, depending upon the texture of the soil and the contour of the surface.

These sidehill ditches are very easily constructed, being made almost entirely with the plow. A bank is formed by running a number of furrows, throwing the dirt toward the middle. The last furrow on the upper side is cleaned out with a spade to form the bottom of the ditch. If the plow is well handled it takes very little work with the spade to make a very substantial ditch. It is well to get the bank forming the lower side of the ditch sodded with grass to help hold it and to lessen the danger of its giving way during a heavy rainfall. When the slope is thus protected with a number of ditches at the proper distance apart, the rows can be given a rather steeper fall so that they shall run out into the drains at frequent intervals and not have to carry the water so far. These ditches have to be constructed with care and have to be strengthened where they cross any depression or sudden curve by building up an embankment with sticks and brush thrown across to support the embankment. Unless these ditches are thoroughly constructed they are worse than useless, for if they break they concentrate a volume of water upon one point in the field which would otherwise have been distributed over the surface, and this often forms a torrent which does great damage.

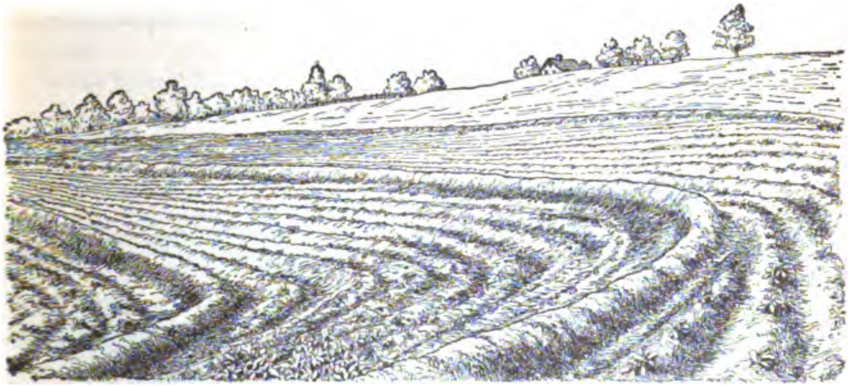


Fig. 3.—Showing construction of sidehill ditches.

It is essential that these ditches and rows be run according to the contour of the surface of the land, and that there shall be no low places where the water would accumulate and gather force. They should always be run with a level; of which there are several forms on the market suitable for this work.

A more efficient, but at the same time much more expensive, method of preventing the washing of lands where there is a considerable slope, is to terrace the fields so that there shall be level steps upon which the water can rest for a while and be absorbed. In terracing the lines are run with a spirit level following the contour of the surface so as to give a perfectly level line. A furrow is run along this line, and a similar furrow is run along a lower contour, the distance apart depending upon the nature of the land and the slope of the surface, as in case of sidehill ditches. Theoretically, it is intended to have the surface between these two furrows level so that there will be no chance for the water to run off over the surface. On a small scale this leveling can be done with a horse shovel, and the land thus put at once into a condition to pre.

vent washing. In this case the banks of the terrace are sodded or seeded with grass to prevent them from washing. In field practice, however, the soil is moved gradually with a plow, the furrow being thrown always downhill and the soil gradually worked down to a level plain. There are several forms of reversible plows which are admirably adapted to this purpose, being turned readily from a right to a left handed plow, so that in going back and forth the furrow is always thrown downhill. It requires, of course, a number of years of such cultivation to get the surface into even approximately a level condition, but with patience and thorough cultivation the soil very quickly assumes a comparatively level aspect, and erosion is reduced to a minimum. This is a more expensive method, but if intelligently done it is much more efficient and much more durable than depending upon sidehill ditches to prevent erosion. As was said in the case of the sidehill ditches, unless this work is well done it had much better be left undone, as it may seriously injure the field.

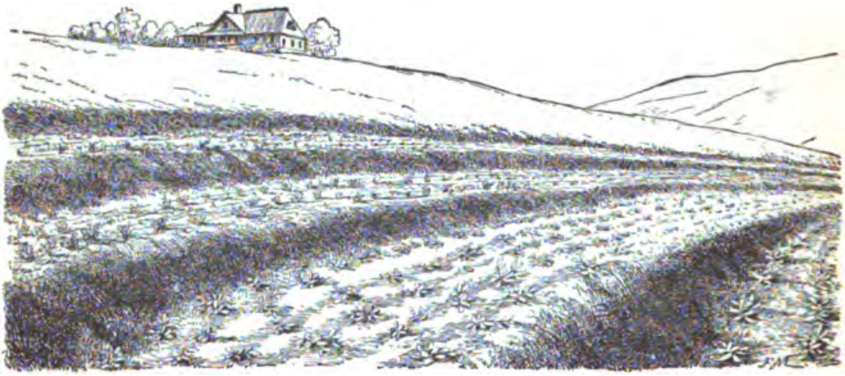


FIG. 4.—Showing method of terracing farm lands.

Where erosion has proceeded so far as to render the land at present unfit for cultivation, or where the land is not needed for cultivation and it is desired to prevent erosion, the land should be given up to trees, herbs, or grasses of some kind according to one or the other of the following methods.

RECOVERING GULLIED HILLSIDES BY REFORESTATION.

Forest ground is not subject to this erosive action of the rainfall because in a forest a large part of the rainfall never reaches the soil, as 20 or 30 per cent is intercepted by the foliage and evaporated before it reaches the ground. The rainfall which reaches the surface is rapidly absorbed, as the soil is kept granular and loose and much more of the water is carried off by underdrainage rather than by surface drainage.

The forest covering protects the soil in the following ways:

(1) By preventing rain from falling directly upon the soil, the foliage

of the tree crowns intercepting and breaking its force, the water reaching the soil more gently from the leaves and along the branches and trunks of the trees.

(2) By interposing a loose cover or mulch of litter formed by the fallen leaves and branches, which breaks the direct force of the raindrops and keeps the soil from being compacted or puddled by their blows.

(3) The deeply penetrating roots, and holes left from decayed stumps and roots of trees, assist in this underground drainage.

(4) The litter with the stumps and projecting roots and trunks of trees prevent the water from rapidly running over the ground and from gaining the momentum and force which is necessary in order to erode and gully the soil.

(5) The forest cover prevents the drifting and the rapid thawing of snow, thereby insuring more even distribution of the waters and an increase in the time during which it can percolate or be absorbed into the soil.

If the forest floor is not disturbed by fire, nor the litter trampled and compacted by cattle, it always reduces rapid surface drainage and largely, if not entirely, prevents erosive action.

RECOVERY OF WASHED SOILS.

Just as deforestation of hillsides and hilltops is the first cause for inducing erosive action, so is reforestation the most effective means in curing the evil. This has been demonstrated in France, where the Government and the farmers together have spent, during the last thirty years, over $40,000,000 and expect to expend three or four times that amount to reforest 1,000,000 acres of denuded mountain sides, the soil and débris from which has been carried by the torrents of water into the plain, covering over 8,000,000 acres of fertile ground and making it useless for agriculture. Sodding for pasture has been found mostly less effective and on the steeper slopes entirely ineffective.

Wherever the ground in the hill country is not fit for agricultural use it should be set and kept in forest, not only to make it produce a timber crop, but also to prevent the erosion which finally becomes dangerous to the lower valley lands. Wherever agriculture is possible and profitable there should be such a distribution of forest, pasture, and field as will secure the greatest immunity from erosive and torrential action of the waters. The forest should occupy all hilltops which, as a rule, have too thin a soil to allow profitable agricultural use; it should be kept growing on the steeper slopes where the water acquires the greatest momentum and the loosening of the soil by the plow furnishes a most favorable condition for erosive action; it should be placed on all rocky, uneven, agriculturally useless spots, because it will produce useful material even on such unfavorable situations, and, finally, forest belts should be maintained on long slopes alternately with fields and pastures, running along the brow of the slope of widths and at distances proportionate to the character of the land and the angle of the slope—on the steeper slopes closer together, on the gentler slopes further apart. These belts, acting as a barrier to break the force of the water, will prevent an undue accumulation of surface waters and will protect to a considerable degree the lower fields from washing. Farmers, therefore, living in the eroded hill country should start upon the work of reforestation with a well-conceived plan. They should determine beforehand which parts ought to be in forest, and which they may reasonably expect to adapt again to agricultural uses. They should understand that they must begin this work at the origin of the evil, at the very tops of the hills where the water begins to gather and acquire its force, and gradually proceed with their work down to the lower levels.

PREPARATION FOR PLANTING FORESTS.

Although cultivation of the soil for tree planting in the manner practiced for field crops is advantageous to the young plants for the first few years of their life, it is by no means necessary, and rough, broken, and stony ground, which could not be plowed and prepared for ordinary field crops can be readily planted in trees. If the ground is in such a condition that it can be plowed, this is decidedly the best method of preparing the land. The plowing should in all cases follow the contour of the hill and be as deep as possible, in order to allow as much water as possible to soak into the soil and so diminish surface erosion and prevent the young trees being washed out. The occasional gullies must be filled with brush and soil, or stones, rubble, and dirt.

In the deeply gullied hill lands, where plowing has become impracticable, other ways must be provided against the further erosive action of the water, which would otherwise be apt to wash out and uproot the plants. For this purpose it is necessary to break the force of the water by constructing brush dams across the gullies, and roughly fill in the latter with stone, gravel, earth, etc., in front and rear if they are shallow, and at least in the rear if they are deeper. Where the ravines are especially deep and wide it may become necessary to supplement and strengthen the rough dam with a loose rubble embankment or a dry wall of stone. A simple and efficient method has been practiced in France, which consists in filling up the ravine with brush placed lengthwise and keeping this down by poles laid across and fastened in the sides of the ravine. The waters are thus allowed to drain off, while the soil carried by them is retained in and over the brush, and in a short time the gulley will fill up of its own accord. Then alders and willows are planted along the edge and soon finish the work of securing the ravine against washing. The means for thus breaking the force of the water in the gullies and changing it from a rushing torrent into a series of gentle falls, and in part from surface drainage into subterranean drainage, and of filling up the gullies themselves will have to be devised in every special case as circumstances permit and the ingenuity of the operator suggests. The brush dam is preferably made of willow, poplar, alder, or other readily sprouting material, which becomes alive and by striking root adds to the firmness of the dam.

It is especially needful, as in all kinds of dams, to fasten the ends securely. According to the steepness, depth, and width of the ravine more or less frequent dams are necessary. The accompanying illustration shows how such work is being done successfully in France. After the brush dams, walls, and other breastworks have been established, the waters may be allowed to do the work of filling up the gullies themselves, which they will do sooner or later, or else, where it can be readily accomplished, the filling may be done by hand.

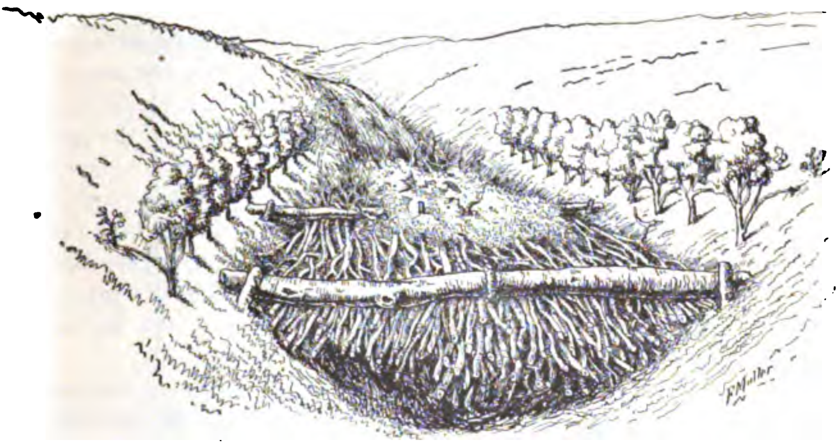


Fig. 5.—Construction of a brush dam.

It must be understood that unless this preliminary work is well done and systematically, beginning at the very tops of the hills where the waters start, it is not worth doing at all, since the water if allowed to get headway would soon wash away and destroy any imperfect work.

PLANTING.

To cover the soil as quickly as possible with a dense and permanent arborescent cover is the object to be attained. Where the soil has not been so far eroded that plowing could be done, it might be best for the first season to sow oats, field peas, or other crops that will readily grow and make a cover. This may be cut for green fodder, leaving a high stubble, and tree seed can be sown broadcast with the fodder crop in the early summer, or over the stubble after the crop is cut in the late summer and fall. The cheapest and most readily germinating tree seed should be looked for and the quantity used per acre should be lavish, to secare a dense stand from the first. The most readily available kinds are the silver or red maple, box elder, elms, ash, and black locust; and since for various reasons variety or mixed woods are preferable, it is advisable to use as many kinds as can be readily obtained.

The soft and red maples ripen their seed in early spring, just about when the leaves are at full size, and should be gathered and sown immediately, as they spoil in a short time. Sown with a field crop they will make a good growth the first year, benefited by the shade of the crop. To provide amply for loss by failure and by destruction when reaping the field crop, not less than three to four bushels per acre of the winged seed should be sown.

The elms ripen their seed in the early summer, by the end of May or beginning of June. As they spoil in a few hours, if allowed to heat in bags, they must be carefully handled and be sown soon after ripening. The same quantity should be sown as of the maples, or somewhat more, and they may be sown after the maples. The box elder is a very hardy and densely foliaged plant which ripens its seed in the early fall. They should be sown soon after ripening at the same rate as the maples. Of the several varieties of ash, the green and white are to be recommended, especially the former, which bears fruit early and plentifully, and is perhaps more hardy than the white. The latter is, however, superior in its timber. The seed ripens by the end of September and the beginning of October, and although it will keep over winter, it is best sown soon after gathering, when the rains and winter snows will carry it through the stubble to germinate next spring.

Finally, with a view to adding a more valuable species, which at the same time is readily procured and propagated, the black locust should be introduced. The seeds ripen in July or August and have the advantage of keeping readily in good condition, and may therefore be sown at any time, but are best used soon after ripening. This species should never be planted alone, because it does not shade the ground well, but when mixed with other shadier kinds, which by their fuller foliage give better soil protection and at the same time reduce the danger from the borer, to which the black locust is otherwise liable, it is one of the most useful species for the purpose, because it grows readily and quickly and suckers and sprouts vigorously, thus insuring a continuous soil cover. With a tolerably dense cover of other species assured, an addition of one or two pounds per acre of locust seed will greatly enhance the economic value of the plantation.

Where the ground is too much cut up and too uneven to permit of plowing, recourse must be had to sowing of seed in plats, or planting of seedlings or cuttings by hand. This is naturally much more expensive, and therefore should be done with greater care and foresight. Plats may be made by loosening the soil with a hoe or spade, and sowing the seed into these seed beds, covering the seed only slightly. The plats should be 3 to 4 feet apart to make sufficiently rapid cover. The success of this method is, however, very questionable, as not only the germinating of the seed under the prevailing conditions is precarious, but rains are apt to wash out the seed or young seedlings. The best success may perhaps be obtained with black locust or oak, the seed of which can be placed deeper (1 to 2 inches) according to soil conditions, with a hope of germinating and avoiding the danger of washing. The surer method, however, will be found in planting seedlings or cuttings. Seedlings are not only expensive but also more precarious to handle, hence for the bulk of the plantation such kinds as can be readily obtained and propagated by cuttings are used, and if desired a sufficient number of seedlings of better kinds can be added to increase the timber value of the plantation.

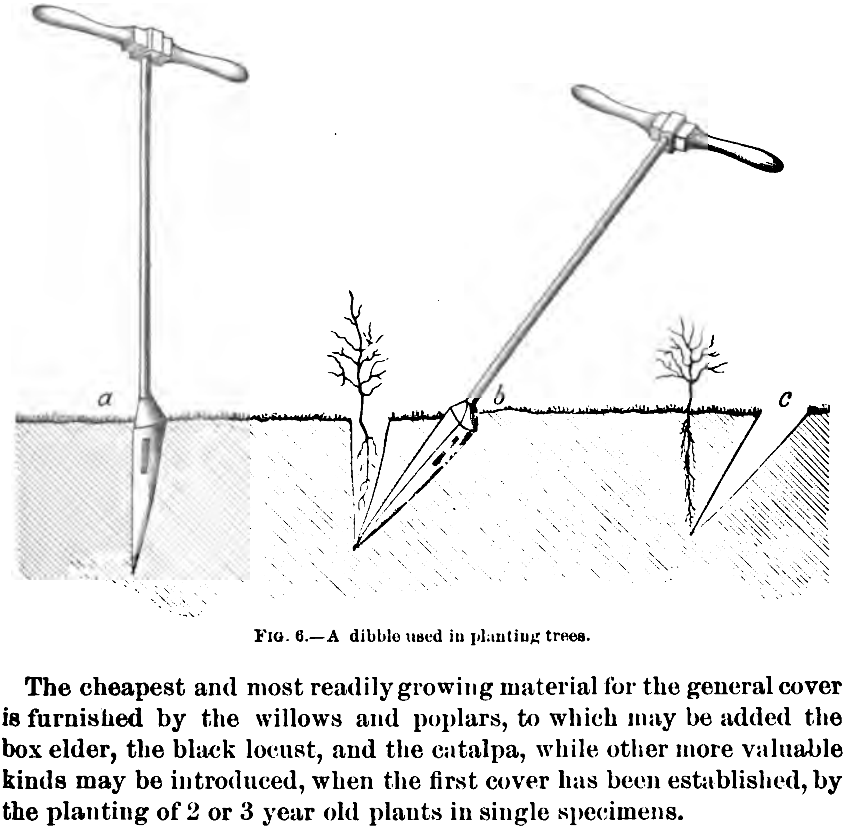


FIG. 6.—A dibble used in planting trees.

The cheapest and most readily growing material for the general cover is furnished by the willows and poplars, to which may be added the box elder, the black locust, and the catalpa, while other more valuable kinds may be introduced, when the first cover has been established, by the planting of 2 or 3 year old plants in single specimens.

The cuttings are best taken in winter before vegetation begins (before the 1st of March), and should be laid in water until planting time, in April; they should be cut 14 or 16 inches long from 3, 2, or even 1 year wood, if of good size, and preferably from the main shoots. For planting, an iron dibble with handle, somewhat like that shown in Fig. 6 is used, and a half conical shoe 12 inches long and 2½ to 3 inches in diameter is also a useful instrument. If the soil to be planted is rather compact and hard, a step may be added—to be used like a spade. The dibble is thrust into the ground to its full depth, loosened and withdrawn; a boy holds the cutting into the hole so that about two or three buds remain above ground; a second thrust somewhat slanting, 2 inches or so from the first hole, and a forward movement closes the hole and plants the cutting, while a few additional short thrusts close the last hole. Two skillful men, with a boy to serve both in placing the cuttings, can plant 3,500 in a day. Seedlings, of course, are planted in the same way.

The first and principal object being to break the force of the surface waters, the arrangement in setting out the plants should be as nearly as possible in horizontal and parallel rows along the brow of the hill, following the contours. To get a full cover as soon as possible the plants should be set not farther apart than 3 to 4 feet and even less, making from 5,000 to 7,000 per acre. If this is found too expensive, or for some reason impracticable to be done at once, the work may be reduced and divided into several seasons; the rows then may be made farther apart, say from 6 to 16 feet, according to the slope, and the plants in the row 2 feet, when the number will be one-half, or less. Additional rows and perhaps of better classes of timber, especially oaks, chestnuts, tulip trees, ash, walnut, and others may be introduced in the following seasons, the soil having come to rest by the first plantings; or else the trees and shrubs grown in the first rows can be utilized to establish a cover by layering their branches. This is done simply by bending down branches, fastening them to the ground by small wooden forks or clamps, and covering a part, say 6 or 10 inches from the end, with soil, when they will strike root and the next year the bent-down branches may be cut loose from the new stock. The branches must be covered with enough earth to insure that sufficient moisture is at their disposal for root formation; covering the buried part with a sod or a stone, which prevents evaporation, is advantageous.

Whatever is done in such a work of recovering lost ground, let this fact never be forgotten, that it is better to do a small part well than a large part indifferently, which usually means lost labor.

GRASSES AND SIMILAR VEGETATION PREVENT EROSION AND WASHING OF AGRICULTURAL LANDS.

On gentle slopes a good turf of perennial pasture grasses, especially those with creeping rootstocks, prevents erosion, or washing, of lands, and short steep embankments may also be protected with this same covering. On longer and steeper slopes, however, this method is not so effective as that of reforestation.

In enumerating the effects to be obtained by the growth of grasses and other herbaceous vegetation on washing lands, or lands liable to be eroded, it should be stated that such growths are calculated to break the force of the rainfall and prevent its packing the soil; to render the ground more porous through the root penetration into the subsoil; to make the soil more absorbent and more retentive of moisture through the addition of humus to the soil from the decay of the plants; to retard the rate with which the surface waters flow off, and lastly, to bind the particles of soil together, which is especially effective in the case of light sandy lands and of newly formed embankments, whether of sand or clay.

The turf which would answer the present purposes should be composed of perennial grasses of varieties which have creeping rootstocks, and it is frequently essential that they be able to grow upon an impoverished and often hard soil. To secure a strong turf on lands of this character it is very important that the soil be put into the best possible condition. Where practicable the soil should be thoroughly plowed or loosened, and some variety of field pea or clover be seeded down, such as the cowpea, Japan clover, or the crimson clover, all well adapted to this purpose. These crops may either be cut off, leaving a high stubble to be turned under, or the whole may be plowed under, thus furnishing a quantity of organic matter to the soil as a preparation for the grasses which are to be seeded. As drought is one of the most serious conditions to be contended with on lands of this character, crimson clover is one of the best of these green manuring crops, as it makes most of its growth in the winter months, when there is less liability of drought. This, however, can not be used too far North, as it does not stand the winters well.

With this preparation of the soil Bermuda grass is one of the best grasses for the purpose of preventing erosion, or of reclaiming eroded land in the South. This should be planted by cutting up a turf rather than by seeding, as the seeds do not germinate very readily, even where they have been gathered in a mature condition. Care must be taken in the introduction of this Bermuda grass, as it is exceedingly troublesome in the cotton field. In the North the English blue grass is one of the best grasses for this purpose, and the Hungarian brome is valuable for the same purpose in both localities.

Where the soil will support other good turf grasses of higher value for hay or pasturage, or where the soil can be brought into a condition to support them, these more valuable grasses should be introduced.

FARMERS' BULLETINS.

These bulletins are sent free of charge to any address upon application to the Secretary of Agriculture, Washington, D. C. Only the following are available for distribution:

No. 15. Some Destructive Potato Diseases: What They Are and How to Prevent Them. Pp. 8.
No. 16. Leguminous Plants for Green Manuring and for Feeding. Pp. 24.
No. 18. Forage Plants for the South. Pp. 30.
No. 19. Important Insecticides: Directions for Their Preparation and Use. Pp. 20.
No. 21. Barnyard Manure. Pp. 32.
No. 22. Feeding Farm Animals. Pp. 32.
No. 23. Foods: Nutritive Value and Cost. Pp. 32.
No. 24. Hog Cholera and Swine Plague. Pp. 16.
No. 25. Peanuts: Culture and Uses. Pp. 24.
No. 26. Sweet Potatoes: Culture and Uses. Pp. 30.
No. 27. Flax for Seed and Fiber. Pp. 16.
No. 28. Weeds; and How to Kill Them. Pp. 30.
No. 29. Souring of Milk, and Other Changes in Milk Products. Pp. 23.
No. 30. Grape Diseases on the Pacific Coast. Pp. 16.
No. 31. Alfalfa, or Lucern. Pp. 23.
No. 32. Silos and Silage. Pp. 31.
No. 33. Peach Growing for Market. Pp. 24.
No. 34. Meats: Composition and Cooking. Pp. 29.
No. 35. Potato Culture. Pp. 23.
No. 36. Cotton Seed and Its Products. Pp. 16.
No. 37. Kafir Corn: Characteristics, Culture, and Uses. Pp. 12.
No. 38. Spraying for Fruit Diseases. Pp. 12.
No. 39. Onion Culture. Pp. 31.
No. 40. Farm Drainage. Pp. 24.
No. 41. Fowls: Care and Feeding. Pp. 24.
No. 42. Facts About Milk. Pp. 29.
No. 43. Sewage Disposal on the Farm. Pp. 22.
No. 44. Commercial Fertilizers. Pp. 24.
No. 45. Some Insects Injurious to Stored Grain. Pp. 32.
No. 46. Irrigation in Humid Climates. Pp. 27.
No. 47. Insects Affecting the Cotton Plant. Pp. 32.
No. 48. The Manuring of Cotton. Pp. 16.
No. 49. Sheep Feeding. Pp. 24.
No. 50. Sorghum as a Forage Crop. Pp. 24.
No. 51. Standard Varieties of Chickens. Pp. 48.
No. 52. The Sugar Beet. Pp. 48.
No. 53. How to Grow Mushrooms. Pp. 20.
No. 54. Some Common Birds in Their Relation to Agriculture. Pp. 40.
No. 55. The Dairy Herd: Its Formation and Management. Pp. 24.
No. 56. Experiment Station Work—I. Pp. 30.
No. 57. Butter Making on the Farm. Pp. 15.
No. 58. The Soy Bean as a Forage Crop. Pp. 24.
No. 59. Bee Keeping. Pp. 32.
No. 60. Methods of Curing Tobacco. Pp. 16.
No. 61. Asparagus Culture. Pp. 40.
No. 62. Marketing Farm Produce. Pp. 28.
No. 63. Care of Milk on the Farm. Pp. 40.
No. 64. Ducks and Geese. Pp. 48.
No. 65. Experiment Station Work—II. Pp. 32.
No. 66. Meadows and Pastures. Pp. 24.
No. 67. Forestry for Farmers. Pp. 48.
No. 68. The Black Rot of the Cabbage. Pp. 22.
No. 69. Experiment Station Work—III. Pp. 32.
No. 70. The Principal Insect Enemies of the Grape. Pp. 24.
No. 71. Some Essentials of Beef Production. Pp. 24.
No. 72. Cattle Ranges of the Southwest. Pp. 32.
No. 73. Experiment Station Work—IV. Pp. 32.
No. 74. Milk as Food. Pp. 39.
No. 75. The Grain Smuts. Pp. 20.
No. 76. Tomato Growing. Pp. 30.
No. 77. The Liming of Soils. Pp. 19.
No. 78. Experiment Station Work—V. Pp. 32.
No. 79. Experiment Station Work—VI. Pp. 28.
No. 80. The Peach Twig-borer—an Important Enemy of Stone Fruits. Pp. 16.
No. 81. Corn Culture in the South. Pp. 24.
No. 82. The Culture of Tobacco. Pp. 23.
No. 83. Tobacco Soils. Pp. 23.
No. 84. Experiment Station Work—VII. Pp. 32.
No. 85. Fish as Food. Pp. 30.
No. 86. Thirty Poisonous Plants. Pp. 32.
No. 87. Experiment Station Work—VIII. (In press.)
No. 88. Alkali Lands. Pp. 23.
No. 89. Cowpeas. Pp. 16.

C

RECEIVE
SEP 21 1914
ivision of Fore
University of Calif

Proceedings of

The First Water Congress of Southern California

held at

Chamber of Commerce, Los Angeles, March 13, 1905

Pursuant to the call of a committee named by the directors of the Chamber of Commerce of Los Angeles, consisting of Prof. A. J. Cook, chairman; Frank Wiggins, secretary; J. S. Slauson, T. P. Lukens, C. B. Boothe and W. C. Mendenhall, delegates from various sections of Southern California assembled at 10 o'clock this date.

The meeting was called to order by J. O. Koepfli, President of the Chamber of Commerce of Los Angeles, who made a brief address, welcoming the delegates. He stated that Chairman Cook being detained by high floods on the line of the Santa Fe Railroad, he would ask C. B. Boothe of the committee to take the chair.

Owing to Secretary Wiggins being occupied with important matters, C. B. Messenger was asked to act as Secretary.

Chairman pro-tem Boothe—Will the Secretary call the roll of Delegates?

REPRESENTING:

San Diego Chamber of Commerce.
R. C. Allen, C. S. Alverson.
Merchants and Manufacturers Association of Los Angeles.
J. M. Schneider, C. H. Plummer.
Santa Ana Chamber of Commerce.
Robert McFadden, John Cubben.
Long Beach Board of Trade.
P. E. Hatch, W. W. Lowe, F. L. Crowe, W. J. Horne, E. E. Hillegas.
Riverside Chamber of Commerce.
Geo. Frost, John G. North, Francis Cuttle, E. A. Chase, W. G. Frazer.
Los Angeles Municipal League.
T. B. Comstock, F. H. Olmstead, C. A. Moody, Hugh Glassell.
Hollywood.
P. J. Beveridge, N. A. Dunny.
Anaheim Chamber of Commerce.
J. B. Rea, C. O. Rust, J. B. Neff.
Ventura Board of Trade.
Geo. S. Barnes.
San Antonio Fruit Exchange, Pomona.
D. C. Teague, L. C. Meredith, C. B. Sumner.
Fullerton Board of Trade.
Alex. McDermot, C. C. Chapman, E. W. Dean.
Tropico Improvement Association.
A. W. Collins.
Los Angeles Chamber of Commerce.
Fred L. Alles, A. P. Griffith, Geo. Chaffee, A. H. Koebig, Mrs. H. W. R. Strong, Wm. Niles, Otis Lockhart.
Pasadena Board of Trade.
T. P. Lukens, S. O. Bowen, W. Scott Way, W. A. Butterworth.
Los Angeles Board of Trade.
J. M. C. Marble.

Santa Ana Valley Irrigation Association.
M. Nisson, S. Armor, A. E. Bennett, Wm. Gregg.
Gardena-Moneta Farmers Club.
O. M. Johnson.
Corona Board of Trade.
E. L. Hazzard..
Queen Colony Fruit Exchange.
W. H. Jamison, A. C. Wood.
Pomona Board of Trade.
Geo. P. Robinson, Walter A. Lewis, C. T. Lorbeer, Frank Seaver, C. E. Tait.
San Gabriel River Water Committee.
Calvin W. Brown, J. T. Lindley, J. R. Elliott.
Chamber of Commerce, Ontario.
B. C. Shepherd.
Glendora Farmers Club.
Geo. D. Whitcomb, C. S. Whitcomb, E. Easley, W. J. Sewards, J. P. Englehart, L. M. La Fetra, W. J. Cox.
Monrovia Board of Trade.
J. H. McClymarck, C. F. Monroe, C. O. Monroe.
California Development Co.
L. M. Holt.
Whittier Citrus Association.
F. A. Fletcher, J. M. Randall.
Verdugo Canyon Water Co.
J. B. Woodbury.
Executive Committee So. Cal. Section Nat'l Irrig. Association.
J. H. Braly.
Independent Water Co. of Glendale.
H. E. Gulvin.
Farmers Club of El Monte.
M. F. Quinn, F. P. Cogswell.
San Antonio Water Co., Ontario.
H. E. Trask.
Marengo Water Co., So. Pasadena.
E. Sorabjee, Supt.
Orange.
A. D. Bishop.
Azusa.
W. R. Powell.

Chairman Boothe—"Ladies and Gentlemen, Delegates to the First Water Congress of Southern California: If Chairman Cook had not been unavoidably detained, he would at this time outline to you the object and purpose of this Congress. As he will undoubtedly be here presently, I will not anticipate what he may say, but proceed with the program as prepared by the committee.

The first paper to be announced is very appropriately by a gentleman who has been one of the first to lead in the investigations upon the subject matters which you are here today to consider. As Resident and Consulting Engineer of the U. S. Reclamation Service, he is qualified to speak with a knowledge second to none, and I take great pleasure in introducing to you J. B. Lippincott, who will take for his topic

MOUNTAIN STREAM CHARACTERISTICS OF SOUTHERN CALIFORNIA.

INTRODUCTION.

The most important question now before the people of Southern California is the water problem. At the present rate of growth which Los Angeles is making, the limit of her present water supply is in sight. If a sufficient supply can be obtained, it now seems probable that at no distant day almost the entire Coastal Plain between Los Angeles and Santa Monica, the area between Pasadena and Los Angeles, and the area east of Pasadena for some miles, will be thickly inhabited. It will become the American Riviera. The limiting factor will largely be the water supply.

This city and vicinity is the Mecca of an ever increasing number of people who wish to escape the rigors and dirt of an Eastern winter. There are many other factors that will tend to increase the population and importance of this locality, but the mild climate and varied topography will always be the greatest.

RAINFALL.

While we can but hope that the long period of low precipitation has come to an end, we should not forget that one of the attractions and a valuable asset of Southern California, is its great number of cloudless days. The average seasonal rainfall at Los Angeles for the 21 years ending August, 1893, was 18.30 inches. The average for the 11 years following that date, that is, from September 1, 1893, to August 31, 1904, was 11.26 inches. The mean precipitation for the entire period of 32 years, during which the record has been kept, is 15.88 inches. The seasons of greatest precipitation were 1883-84 and 1889-90, when the totals were 38.26 in. and 34.60 in. respectively. There have been four seasons when the precipitation was approximately 1-3 of the mean, and six when the precipitation was about 2-3 of the mean.

Considering the fact that the mean precipitation was more than 18 inches up to 1893, it is not surprising that engineers at that time, and for a number of years after, estimated the stream flow or run off too high.

Anyone who has made a study of a diagram showing the rainfall at Los Angeles and Santa Barbara cannot but be impressed with the great fluctuation in the precipitation. Such a diagram emphasizes the necessity for conserving the water supply in years of abundance.

POSSIBILITIES AND MEANS OF CONSERVING THE WATER SUPPLY

The water supply can be conserved by forestration and storage of flood waters in surface and underground reservoirs.

Much money has been spent in Southern California in driving water development tunnels (in the mountains). As a means of obtaining a permanent supply this method of development has been generally disappointing. The flow from the tunnel for a comparatively short period of time is greater than the natural flow of the spring or cienega. This increase is due to the rapid drainage of the water stored in the crevices of the rocks or gravels. In order to keep up the supply, the tunnels usually were extended. Manifestly this cannot be a permanent remedy.

An improvement on this method was recently made at the Santa Barbara City tunnel, which has been driven in a stratified sandstone for a length of 5000 feet. A water-tight bulkhead with a gate was placed near the tunnel portal and the gate closed during the rainy season, and the water allowed to accumulate when not needed. During the winter of 1902-3 there was a fair amount of rainfall and the streams were capable during that time of meeting the demands of the city. As soon as the bulkhead could be closed this was done—about July 1, 1903. Because of the fissured condition of the rock in the tunnel it was not feasible at the point where the bulkhead was first placed to completely close the supply from the heading, as springs occurred below the bulkhead toward the portal, flowing in considerable volume. However, the pressure ran up to 49 pounds to the square inch on July 25th, as indicated by the pressure gage placed in the discharge pipe, indicating an accumulated head of water back of the bulkhead of 114 feet. This shows that the tunnel was developed into a storage reservoir. The gate valve in the bulkhead was gradually opened as the season progressed, and the supply maintained a flow of from 24 to 33 miner's inches during the remainder of the summer. On October 17th, when the valve was completely opened and the pressure has been reduced to zero, the flow had fallen to 18 miner's inches. This was sufficient to carry the city through the summer successfully.

During the summer of 1904 a new bulkhead was placed at a point in the tunnel where a heavy clay seam occurs in the rock. This new bulkhead was more effective than the first one constructed in holding back the water. The pressure on the gage at the Santa Barbara tunnel March 1, 1905 was 70 pounds to the square inch, representing a head of 161 feet on the bulkhead.

Another method of intercepting the ground water has been by building submerged dams. Such dams have been constructed on the Pacoiwa Wash, the Arroyo Seco and Santiago canyon. This method has been disappointing, as the velocity of underground water has been proven very slow, usually not over 15 feet per day through the voids of sand and gravel. A method of measuring the flow of underground water has been developed by the Geological Survey by Prof. C. S. Slichter. For a description of this method, see Water-Supply and Irrigation Paper No. 67.

FORESTRATION.

One of the most efficient means of conserving and regulating the water supply that falls on the mountains is by forest cover. The great importance of preserving and extending the forested area cannot be too strongly emphasized. The fires must be prevented, for in this region bordering closely on desert conditions, artificial forestration is most difficult and expensive.

Mr. James W. Toumey, Collaborator Bureau of Forestry in the Agricultural Department, selected certain small and adjoining drainage basins in the San Bernardino Mountains in a portion of the catchment area proposed to be utilized by the Arrow Head Reservoir Company. Throughout this area this corporation for a term of years has been making exhaustive hydrographic studies of the available water supply. A large number of rain gages have been established and stream measurements were carefully made over weirs by skilled engineers in the employ of the Arrow Head Reservoir Co. It is here proposed by the Company to divert the water flowing from a number of these small mountain basins which are situated on the northerly slope of the San Bernardino Range by means of gravity canals and tunnels to the southern side of the range and into the San Bernardino Valley.

The Arrow Head Reservoir Company has placed its hydrographic data at the disposal of the Bureau of Forestry, which organization made the forest study in connection therewith. The data that is presented by Mr. Toumey is perhaps the most precise and definite information on the subject of related stream flow to forest cover that we have so far been favored with in this country. His conclusions, while they were to be expected, are gratifying in their definiteness. We can do no better than to quote from Mr. Toumey in extenso:—

"Because rainfall is most abundant where forests grow, many believe that forests exert an important inference on the amount of precipitation. A more reasonable influence, however, is that **rainfall is the great factor in controlling the distribution and density of forests.**"

"Whether forests have any appreciable effect in cooling the air to below the dew-point is uncertain. From the known effect of forests on the temperature and relative humidity of the air, it is reasonable to infer that they may have some such effect, at least to a small degree, and consequently that they have some influence in increasing precipitation. The present evidence, however, derived from many series of observations conducted in Europe and elsewhere, is so conflicting that a definite answer to this question, having the stamp of scientific accuracy, is not possible."

In a careful study of the behavior of the stream flow on several small catchment areas in the San Bernardino Mountains, it has been found that the effect of the forest in decreasing surface (flood) flow on small catchment basins is enormous, as shown in the following tables, where three well-timbered areas are compared with a non-timbered one:

Precipitation and run-off during December, 1899:

Area of catchment basin	Condition as to cover	Precipitation	Run-off per sq. mile	Run-off in percentage of precipitation
Sq. Miles		*Inches*	*Acre Feet*	*Per Cent*
0. 70	Forested	19+	36—	3
1. 05	Forested	19+	73+	6
1. 47	Forested	19+	70—	6
. 53	Non-forested	13—	312+	40

"This is the stream discharge during a month of unusually heavy precipitation."

"At the beginning of the rainy season, in early December, the soil on all four of these basins was very dry as a result of the long dry seasons. The accumulation of litter, duff, humus, and soil on the forest-covered catchment areas absorbed 95 per cent. of the unusully large precipitation. On the non-forested area only 60 per cent. of the precipitation was absorbed, although the rainfall was much less."

Rainfall and run-off during January, February and March, 1900:

Area of catchment basin	Condition as to cover	Precipitation	Run-off per sq. mile	Run-off in percentage of precipitation
Sq. Miles		*Inches*	*Acre-Feet*	*Per Cent*
0. 70	Forested	24	452+	35
1. 05	Forested	24	428+	33
1. 47	Forested	24	557+	43
. 53	Non-forested	16	828+	95

"The most striking feature of this table as compared with the previous one is the uniformly large run-off as compared with the rainfall. This clearly shows the enormous amount of water taken up by a dry soil, either forested or non-forested, as compared with one already nearly filled to saturation. During the three months here noted, on the forested basins about three-eighths of the rainfall appeared in the run-off, while on the nonforested area ninteen-twentieths appeared in the run-off."

RAPIDITY OF DECREASE IN RUN-OFF AFTER THE CLOSE OF THE RAINY SEASON.

Area of catchment basin	Condition as to cover	Precipitation	April run-off per sq. mile	May run-off per sq. mile	June run-off per sq.mile
Sq. Miles		*Inches*	*Acre-Feet*	*Acre-Feet*	*Acre-Feet*
0. 70	Forested	1.6	153—	66—	25—
1. 05	Forested	1.6	146—	70+	30—
1. 47	Forested	1.6	166+	74+	30+
. 53	Non-forested	1.	56+	2—	.0

"The above table clearly shows the importance of forests in sustaining the flow of mountain streams. The three forested catchment areas, which, during December, experienced a run-off of but 5 per cent. of the heavy precipitation for that month, and which during January and March of the following year had a run-off of approximately 37 per cent. of the total precipitation, experienced a well sustained stream flow three months after the close of the rainy season. The non-forested catchment area, which, during December experienced a run-off of 40 per cent. of the rainfall, and which during the three following months had a run-off of 95 per cent. of the precipitation, experienced a run-off in April (per square mile) of less than one-third of that from the forested catchment areas, and in June the flow from the nonforested area had ceased altogether."

Annual rainfall and run-off on forested and nonforested catchment areas in the San Bernardino Mountains, California:

Area of catchment basin	Condition as to cover	Precipitation	Run-off per sq. mile	Run-off in percentage of precipitation
Sq. Miles		*Inches*	*Acre-Feet*	*Per Cent*
0.70	Forested	46	731	28
1.05	Forested	46	756	30
1.47	Forested	46	904	36
.53	Non-forested	33	1,192	69

In conclusion it may be stated that while there is little definite scientific information that forests increase rainfall, we have certain srtiking instances presented where the rainfall is greater on adjacent forested areas than on those that are denuded. At least in the arid regions, it may be stated that the total annual output from a de-forested drainage basin is greater than from a timbered area, but that the regimen of the stream is distinctly to the disadvantage of all who are interested in the use of the watered resources of the country, whether he be domestic water supply engineer, irrigator, or water power investor. From the denuded area the floods are greater and the drought is more intense. To remedy this condition one naturally turns to the storage reservoir for relief, yet even in this extremity one is confronted with adverse conditions. The violent flood from the bare basin rushing through the mountains carries with it eroded sediment which it deposits in the first pool of still water that it encounters. The result is the reduction of the storage capacity of the reservoir along its course. Forests are the natural and greatest storage reservoirs and regulators of water supply. On few streams do we find reservoir capacities even approximating the total annual output of the drainage basins above them. The evaporation from storage reservoirs is usually great, often equalling 20 per cent. of their capacity annually. Accepting the facts as outlined above, the great importance of preserving the forests, particularly in the semi-arid regions of our country, is most manifest. In Southern California, Arizona, and New Mexico, particularly, we are so closely bordering on a condition of desert that when the forest is once destroyed the difficulty of reproducing it renders the task well nigh hopeless. We should therefore all join with the Bureau of Forestry in its efforts to save the forests and thus store the flood.

REGIMEN OF CALIFORNIA RIVERS.

The following table gives the mean monthly flow of nine California streams for four months of greatest run-off and the percentage this bears to the total annual run-off. This table illustrates the great importance of the Colorado River as a source of water supply for irrigation. A study of this table shows that this stream is better adapted for this purpose than any other in California, because its maximum flow comes nearer to coinciding with the season of greatest need. In addition to this, its waters carry a large amount of fertilizing silt. The table also shows the importance of storage reservoirs and forest cover in regulating stream flow particularly in Southern California.

Table showing the Mean Monthly Flow for Four Months of Greatest Run-Off of Nine California Streams and the Percentage this bears to the Total Annnual Run-Off.

Stream	Length of record used	DISCHARGE IN ACRE-FEET								Total for 4 mo. of greatest Flow in Acre-feet	% of Total Mean Annual Flow
		January	February	March	April	May	June	July	August		
San Gabriel	9 yrs		8,260	9,190	9,770	4,850				32,070	70%
*Santa Ana	8 yrs		4,140	4,440	5,480	3,030				17,090	48%
**Mojave	5 yrs	4,840	12,840	9,210	9,770					36,660	58%
Sacramento	9 yrs	1,189,600	1,551,400	1,594,800	1,083,700					5,419,500	55%
Tuolumne	9 yrs			198,700	290,600	455,300	398,400			1,343,000	71%
San Joaquin	7 yrs				246,200	488,900	463,100	166,600		1,364,800	71%
Kings	9 yrs				217,500	473,400	463,300	144,300		1,298,500	75%
Kern	8 yrs				86,100	135,800	113,400	57,800		393,100	65%
Colorado	3 yrs					1,996,200	2,766,600	497,300	659,900	6,920,000	71%

*Partly regulated by Bear Valley Reservoir.
**Partly regulated by gravel bed above Victor Narrows.

UNUSED STORAGE RESERVOIRS.

The mountains and foothills of Southern California are usually so precipitous that there are few unused reservoir sites where the storage capacity is sufficient to justify the expenditure of money necessary to construct the impounding works. The capacity of the sites that exist are relatively small. In some instances the water supply in insufficient to fill the storage basins. Reservoir sites are more numerous in San Diego and Santa Barbara Counties.

The history of the principal reservoirs that have been constructed in Southern California is too well known to be given here. I will mention briefly some reservoir sites that, on account of the great value of water are worthy of consideration.

WARNER RANCH RESERVOIR SITE.

This site is located on the San Luis Rey River. The area of the water-shed above the dam site is 210 square miles, all to the east of the main crest of the coast range. The estimated capacity of this reservoir is 193,200 acre-feet on the 100-foot flow line. If this reservoir had been constructed, it would probably have been dry or nearly so for a number of years past. The Escondido Irrigation District has the prior right on this stream. A gaging station has recently been established on the San Luis Rey River near Pala that will determine approximately the amount that will be available for filling the Warner Ranch Reservoir. The gaging station is located below the intake of the Escondido Irrigation District.

ARROW HEAD RESERVOIR SITES.

The Arrow Head Reservoir Company has been making a careful study of the available water supply on the head waters of the Mohave River since 1892. The plan of this company contemplates the storage of the run-off from 78 square miles of mountain water-shed, which has an elevation of 5,000 feet or over. The principal reservoir site is located at Little Bear Valley. The construction of the dam at this point is now under way. The capacity of this site at 160 feet above the stream bed is 60,179 acre feet.

Two other reservoirs are contemplated, one at Grass Valley, with a capacity of 27,547 acre-feet, and another at Huston Flat, with a capacity of 24,753 acre-feet. The plan contemplates the diversion of the water from these reservoirs into the San Bernardino Valley. The tunnels on the diversion line have been completed. The stream measurements that have been made by the Arrowhead company have not been made public. While they have been disappointing they are said to justify the construction of the main reservoir.

VICTORVILLE RESERVOIR SITE.

This site is located on the Mohave River in San Bernardino County, just above the town of Victorville, California. The main line of the Atchinson, Topeka & Santa Fe Railway passes through the reservoir and through the gorge at the dam site. Before this reservoir could be utilized 5½ miles of new track would have to be built. This is without doubt the most capacious reservoir site in Southern California. The capacity has been estimated at 390,000 acre-feet at a point 145 feet above the stream bed. The Geological Survey established a gaging station at this point on February 27, 1899. The average flow from 1900 to 1904, inclusive, has been 62,948 acre-feet. The underflow has been determined by the Geological Survey to be about one second-foot.

DISCHARGE OF MOHAVE RIVER AT VICTORVILLE, CAL.

Year	Acre-feet
1900	32,204
1901	103,820
1902	36,756
1903	107,842
1904	34,121
Mean	62,948

LA CANADA RESERVOIR SITE.

A reservoir site exists on the La Canada above its junction with the Arroyo Seco, Los Angeles County. This site has a capacity of 3200 acre-feet at the 90-foot flow line. The drainage area tributary to the site is 27.6 square miles. Some water could be obtained by diverting the flood flow of the Arroyo Seco to it, but these waters are now nearly absorbed by the gravel beds above Devil's Gate and are then collected by the City of Pasadena. In wet years this reservoir might be filled and its water used to supplement existing supplies for the City of Pasadena, and thus be used to conserve the water stored in the gravel beds and save on pumping bills.

TRIUMFO AND MALIBU RESERVOIR SITES.

Reservoir sites of considerable value exist on these streams. The water from these reservoirs could be used to partly supply the lower foothill lands from Hollywood to Santa Monica, by a gravity system of conduits.

RESERVOIR NO. 1:

The drainage area above Reservoir No. 1 is 68 square miles of low mountains. The rainfall has not been measured. To meet drought conditions the reservoir capacity should be large enough to hold a three years supply so as to hold over from years of plenty to years of drought. The flood waters from these streams waste into the ocean west of Santa Monica. A gaging station has been established by the Geological Survey to measure the stream discharge. A dam 100 feet high would be about 20 feet long at the base and 150 feet on top, and it is roughly estimated would hold 21,000 acre-feet of water. This is an unusual dam and reservoir site for Southern California. It is reported that a dam is now being built near the head of this stream to store flood water for local irrigation

RESERVOIR NO. 2:

This site would command the same canal line as No. 1. The drainage area above this site is 37 square miles of similar country as that above No. 1. A gaging station has also been located upon this creek. The dam should be built so as to hold a three years' supply. These flood waters now waste into the Pacific. A dam 140 feet high would be about 50 feet long at base and 450 feet long on top, and have a capacity roughly estimated at 9000 acre-feet, or 416 miner's inches, for six months' flow.

ESTIMATED MONTHLY DISCHARGE OF MALIBU CREEK BELOW THE MOUTH OF THE TRIUMFO NEAR CALABASAS, CAL., FOR 1903-04.

(Drainage area 97 square miles.)

1903	Total in Acre-feet	1904	Total in Acre-feet.
Jan.	523	Jan.	307
Feb.	872	Feb.	316
Mar.	2,828	Mar.	424
Apr.	7,188	Apr.	179
May	578	May	135
June	327	June	89

July	160	July	——
Aug.	——	Aug.	——
Sept.	——	Sept.	——
Oct.	——	Oct.	61
Nov.	119	Nov.	71
Dec.	252	Dec.	301
The Period	12,847	The Period	1,883

ESTIMATED MONTHLY DISCHARGE OF TRIUMFO CREEK NEAR CALABASAS, CAL., FOR 1903-04.

(Drainage Area 72 Square Miles.)

1903	Total in Acre-feet.	1904	Total in Acre-feet.
Jan.	203	Jan.	184
Feb.	644	Feb.	178
Mar.	1,691	Mar.	295
Apr.	3,570	Apr.	104
May	461	May	37
June	208	June	——
July	123	July	——
Aug.	——	Aug.	——
Sept.	——	Sept.	——
Oct.	——	Oct.	——
Nov.	36	Nov.	——
Dec.	123	Dec.	——
The Period	7,059	The Period	798

PIRU CREEK RESERVOIR SITES.

There are two reservoir sites on Piru Creek in Ventura County. This creek is a tributary of the Santa Clara River. Its summer flow is diverted for irrigation in the Piru Canyon and near Piru City. The impounded flood water could be conveyed down the Santa Clara Valley. A large amount of flood water runs to waste from this water-shed. One site known as the Piru Reservior, is located at the junction of Rays and Lockwood Creek. A dam 140 feet high would furnish a capacity of 13,160 acre-feet. The other reservoir is located at Lockwood Valley on Lockwood Creek. A dam here 125 feet high would give a capacity of 14,857 acre-feet. The drainage areas tributary to these sites are 139 and 55 square miles, respectively. The drainage area is all above 4,000 feet elevation, and a portion of it is over 5,400 feet. The precipitation in the Piru basins was about 75 per cent. of that in the San Gabriel. The flow of Piru Creek occurs largely in flood waves. In mid-summer it is but a few inches and during the winter season floods of 6,000 second-feet have been measured at the Piru dam sites. Because of dry years these sites should be so managed as to hold over water from wet years. Measurements of stream flow have been made by the Antelope Valley Water Co.

RESERVOIR SITES IN THE SANTA YNEZ DRAINAGE BASIN IN SANTA BARBARA COUNTY.

There are five reservoir sites located in this basin that have been surveyed and their capacities determined. These are the Juncal, drainage area 13 square miles, capacity at 100 foot flow line, 3,222 acre-feet; Main River, drainage area 71 square miles, capacity of 65 foot dam 4,023 acre-feet; Mono reservoir site, drainage area 119 square miles, total capacity at 100 ft. flow line 8,763 acre-feet; Quicksilver Mine Reservoir site, capacity at 90 ft. flow line 10,577 acre-feet; Gibraltar reservoir site, located 6 miles below the mouth of Mono Creek on the Santa Ynez River, drainage area 207 square miles, capacity at 140 ft. flow line 15,793 acre-feet. This site is below all the others. The discharge of the Santa Ynez river is in floods. as in the case of' other Southern California streams. It is estimated that owing to prospective drought conditions provision for a 19 months supply should be made. The stream flow has been measured now for three seasons and clearly indicates that on this basis the full capacity of at least the Gibraltar site could be safely used, yielding a continuous flow of 650 miner's inches on the above assumption. This would supply the city and leave 500 inches of water for irrigation. The water will have to be conveyed in a tunnel four miles long under the coast range. This tunnel is now being built by the City of Santa Barabara an dthe reservoir site has been purchased.

The following measurements of discharge have been made:

1902-03	21,200 acre-feet
1903-04	4,194 acre-feet
1904-05.	57,127 acre-feet

For particulars in regard to the reservoir sites mentioned above, see Water-Supply and Irrigation Paper, No. 116.

STORAGE OF WATER IN UNDERGROUND RESERVOIRS.

In April and May, 1903, a series of measurements were made by the U. S. Geographical Survey to determine the amount of storm water being absorbed in the sand and gravel washes of the larger tributary streams of the three principal river basins of Southern California, viz, the Santa Ana, San Gabriel, and Los Angeles Rivers. Measurements were taken at the mouths of the canyons where the streams leave the mountains, at all canal diversions, and at such intervals along the streams as time and the available force detailed for this work would allow, the location of the point where the stream entirely disappeared or left the valley being noted in all cases.

STORM WATER DISCHARGED FROM TRIBUTARY STREAMS AND SINKING IN THE LOS ANGELES RIVER BASIN ABOVE BURBANK, CAL.

(Discharge for 24 hours.)

STREAM	ACRE-FEET Diversions	 Waste	 Total
April 18, 1903			
Big Tujunga	....	311	311
Little Tujunga	....	54	54
Pacoima	....	194	194
Total	....	559	559
May 5, 1903			
Big Tujunga	....	73	73
Little Tujunga	....	8	8
Pacoima		48	48
Total	....	129	129
June 4, 1903.			
Big Tujunga	6	18	24
Little Tujunga	....	1	1
Pacoima	6	10	16
Total	12	29	41

STORM WATER DISCHARGED FROM TRIBUTARY STREAMS AND SINKING IN THE SAN GABRIEL BASIN ABOVE EL MONTE, CALIFORNIA.

(Discharge for 24 hours.)

STREAM	ACRE-FEET Diversion	Waste	Total	PASSING EL MONTE Acre-feet
April 26, 1903				
San Gabriel	79	565	644	454
San Dimas	..	38	38	....
Dalton	..	18	18	....
Santa Anita	..	79	79	....
Eaton Canyon	..	57	57	....
Total	79	757	836	454
May 23, 1903				
San Gabriel	139	192	331	....
San Dimas	1	4	5	....
Dalton	2	3	5	....
Santa Anita	6	20	26	....
Eaton Canyon	6	6	12	....
Total	154	225	379	....

STORM WATER DISCHARGED FROM TRIBUTARY STREAMS AND SINKING INTO THE SANTA ANA RIVER BASIN ABOVE COLTON, CALIFORNIA.

(Discharge for 24 hours.)

STREAM	Diversions	ACRE-FEET Waste	Total
April 24, 1903			
Santa Ana	32	230	262
Mill Creek	10	67	77
Plunge Creek	..	46	46
City Creek	..	44	44
East Twin Creek	..	20	20
West Twin Creek	..	17	17
Lytle Creek	14	111	125
Total	56	535	591
May 16, 1903			
Santa Ana	93	95	188
Mill Creek	97	38	135
Plunge Creek	12	6	18
City Creek	14	8	22
East Twin Creek	4	6	10
West Twin Creek	4	4	8
Lytle Creek	30	28	58
Total	254	185	439

These gravel beds are the natural and most available storage reservoirs in Southern California.

There is a demand for all water that can be developed or conveyed to Southern California. Our arid lands are far in excess of our water supply. I believe that we have now over-developed the underground supplies. Practically all the unused storage reservoirs of value in Southern California have been mentioned above and they are all urgently needed to meet local demands, and practically all will be built. While I can not here present the details of a plan to meet this situation in and around the City of Los Angeles, I feel safe in saying that it can and will be properly met, and though the cost will be high it can be made a paying business proposition. We should rather obtain and control a new supply than take by condemnation neighboring waters now required and used.

Chairman pro tem Boothe: The chairman of the committee, Prof. A. J. Cook, has arrived and will now take the chair.

Chairman Cook: Ladies and Gentlemen, I regret exceedingly my late arrival, which, I assure you, is entirely involuntary and is due to the irregularity of the "Santa Fe Ferry" in this glorious down pour which we are getting this morning.

Discussion on the excellent paper which has just been read will be deferred for the present. We will now listen to a paper by W. C. Mendenhall of the U. S. Geological Survey on the topic

UNDERGROUND WATER SUPPLY OF SOUTHERN CALIFORNIA

Introduction.

This Water Congress has been called by the Los Angeles Chamber of Commerce in order to promote a full discussion of the water situation in Southern California. By such a discussion it is hoped that we may reach an understanding of the conditions governing the supply of that resource which is fundamental to all our growth and that we may so shape our future policy as to conserve and utilize this resource to the best possible advantage. By bringing together representatives of the various cities and communities in this common quest, we foster the sense of kinship and advance the principles of co-operation, so necessary in modern times to the accomplishment of any worthy end.

In arid and semi-arid regions, growth is controlled by water supply, so that water becomes the essence of the communities' existence. It is therefore most appropriate that meetings like this should be called from time to time, so that experiences may be compared, ways and means for conserving and increasing the supply discussed, mutual understandings reached where interests conflict—in short, so that each may profit by the experience of all.

We need waste no words in this center of advanced hydraulic engineering and careful irrigation practice upon the value of the product which we are here to discuss. Our presence proves that we understand that. A valley which supports 400,000 people upon 225,000 acres of irrigated land and will support five times that many in the near future, may be expected to know the worth of a drop of water.

What we desire today is to reach a thorough understanding of the sources and the quantity of our supply, the possibilities of increasing it, or utilizing it to better advantage, so that we may plan for the future along such carefully determined lines that the very utmost may be made of our resources without exhausting them. We wish the best possible present for Southern California, and the best possible future. Neither should be neglected for the benefit of the other nor developed at its expense.

INCREASED UTILIZATION OF WATERS.

As Southern California emerged from its quiet pastoral life with the incoming of the great railways, and slowly awakened to a sense of its possibilities with irrigation, the surface waters diverted first from the convenient areas of low-lying moist land, whence ditches could be constructed at little cost, and later from the mountain canyons, where more expensive construction was required, came gradually to be very fully utilized. By 1880 the available flowing waters had been generally diverted, and the limit seemed to have been reached to the amount of land reclaimable from this important source; but the stimulus of the very high values reached by the citrus lands, and the comparatively small acreage under cultivation, as compared with that reclaimable if water were available, combined to induce a most thorough examination of all possible sources.

Two possibilities proved sufficiently attractive to invite the attention of capital and skilled service. The first of these was the storage of flood waters, whose escape to the sea during heavy winter rains has always been a source of deep regret to irrigators. The second was the recovery of underground waters, stored in the subterranean basins or percolating seaward through the sands and gravels beneath the stream channels.

The generally constricted character of the San Bernardino and San Gabriel mountain canyons has been unfavorable to the construction of reservoirs. Actually but two important projects have been completed; the Bear Valley dam, whose stored waters have added the flourishing Redlands colony to the reclaimed areas; and the Hemet Dam, less favorably situated as regards rainfall, and less successful therefore in the matter of acreage redeemed. Another project, the Arrowhead, is under way after years of patient observation of rainfall and run-off, hence eventually there will be a further addition to the waters conserved in this way.

PARTICULAR IMPORTANCE OF THE UNDERGROUND WATERS.

The possibilities for the development of underground waters have proven much greater. It had been found in the sixties and early seventies that artesian waters could be secured from many of the moist land areas, and under the spur of the rapid growth of the eighties and of the past few years and because of the drought of the last decade, these underground waters have been extensively developed until now they are by far the most important single source of irrigation water in this part of the state. The developments have revealed fourteen or fifteen artesian basins underlying lands whose extent at the close of the wet decade ending with 1894 was about 375 square miles, or somewhat more than the total irrigated acreage at present. Much development of ground waters has also taken place without the artesian areas, the increasing value of the lands and crops, the discovery of a cheap fuel oil, the perfection of the gasoline engine and the introduction of electrical power, making it perfectly feasible to irrigate with pumped waters.

The result to date of this activity has been the investment of nearly $5,000,000 in 11,000 wells and their installation. Nearly 3,000 of these wells are artesian at the present time, about 1600 are equipped with pumping plants, and the remainder are smaller domestic wells. The total yield from these wells which are used in irrigation is estimated to be from 400 to 500 second feet, while the surface water thus used during the period of minimum flow in midsummer, amounts to but half as much. The importance of the underground waters in Southern California may be realized from these figures.

CONTROLLING GEOLOGIC CONDITIONS.

The geological conditions which have made possible such extensive and valuable subterranean storage are worthy of a brief sketch. The diversified lowland which constitutes the valley of Southern California may be best described as a series of deep irregular crystal troughs, parellel to each other and to the Pacific shoreline, plunging to the northwest and abutting in this direction against the granitic San Gabriel range. At the foot of this range the ridges separating the troughs are lowest, and here a practically continuous valley extends from Santa Monica to San Bernardino. Farther south the separating ridges rise higher, and the valley is broken by mountain chains and groups. As these troughs and their separating ridges have been formed by geologic processes, the rivers have maintained their way across them from the higher mountains where they rise, to the sea, and in maintaining these courses have cut canyons in the ridges and have filled the troughs with sands, gravels and clays that are products of their erosive action. The result is a series of deep valleys filled with alluvium, across which the rivers flow. These great filled depressions, whose gravels are kept saturated by the waters which flow over them, are nature's storage reservoirs. They are the basins whence the water has been drawn that has carried this part of the State so successfully through the past ten years of drought, and has enabled it to continually increase its acreage during this trying period.

HIDE AND SEEK RIVERS.

It is these basins which give to the rivers the hide and seek habit which is characteristic of them all. The Santa Ana flows as a surface stream from its upper canyon and sinks at once in the coarse debris above Redlands. It is forced to the surface again at Bunker Hill, sinks after it has passed the "dike" there, is forced out again at Riverside Narrows, sinks again in its wash above and below Yorba, and partly rises once more in the strong peatland springs between Santa Ana and the Coast.

The San Gabriel likewise sinks as it emerges from its upper canyon, is forced to the surface at it passes through the Paso de Bartolo, sinks in the Coastal plain below, and rises finally in the sloughs and springs of Alamitos.

The Los Angeles river waters sink at the mouths of the various rock canyons which enter San Fernando Valley; rise in the narrows above the city, sink in the costal plain below, and rise in the springs at the head of Ballona Creek and in the marshes near Long Beach.

Thus the circulation goes on, a part of it at the surface, visible, concentrated, relatively rapid, another part below the surface, hidden, diffused, and relatively slow. The points where the waters are forced to the surface are the points where the principal canals head. They receive the waters here, filtred, protected from contamination and evaporation by their underground journey, and issuing in constant volume, the gravels acting as great regulators as well as in the capacity of storage reservoirs.

The regulating effect which these deep gravel filled basins have upon the underground circulation is like that of a string of lakes upon the flow of a great stream through them. Engineers understand that however violent the floods may be at the head of such a stream, the flow from the last of the lakes will be practically constant. The volume of water at Niagara does not vary because of floods at Duluth. So, the volume of springs near the sea will show no change because of cloudbursts in the San Bernardino Mountains, although the latter waters may eventually issue at the springs.

SOURCE OF THE UNDERGROUND WATERS.

It will be clearly understood from this outline that the underground waters, as well as the surface waters, are merely a part of the rainfall on its return journey to the sea. The theories frequently advanced to the effect that the abundant underground waters in this part of the state may be oceanic waters drawn inland by some mysterious exaggeration of the law of capillarity, and freed of their salt en route, or that they may be

Colorado river, or Sierra or Mohave Desert waters, which have penetrated hundreds of miles of rock of such a character as to make a most efficient dam when but a few feet thick, can have no possible basis in fact. They usually result from attempts to account for phenomena which are not understood, by an explanation which does not explain.

The water in the deep basins filled with saturated alluvium which constitutes the underground supplies from which we are drawing, represents long continued accumulation. The rainfall of one season or of many seasons would not be sufficient to refill these basins were they drained. Actually the water has probably accumulated there as the alluvium itself has been deposited in the troughs.

PHENOMENA OF DECLINE.

During the last few years especially, water users, dependent upon the underground sources, have observed phenomena which have caused some anxiety. The large irrigating and domestic companies have been affected through the lessened flow of surface streams upon which they formerly depended for a large part of their supply, or through the diminished yield of wells and the necessity of installing pumping plants where originally naturally flowing waters sufficed.

Local users, ranchers and others have found that lands formerly moist enough for pasture and ordinary crops are now dry and require irrigation, and that domestic wells must be frequently deepened in order to follow the declining ground water. In some cases the question of supply is becoming acute, and the increased cost of water almost prohibitive for certain crops in unfavorable localities.

In the region about Redlands and San Bernardino, the Survey has found an average decline of somewhat more than 15 feet, in each of 75 wells, during the four years from 1900 to 1904. Among the 75 wells are a few in which the water has risen and others in which the loss has been as much as 50 or 60 feet. Even greater losses are reported in some of the wells along the foothills eastward from here, while in still other areas there has been no loss or even a slight gain. Each community, therefore, has special conditions of its own, depending upon its situation in relation to supply, and upon the amount of development which has taken place in it. Where the tributary drainage basin is large and comparatively little development has taken place, conditions are excellent. Where the tributary drainage basin is small and development has been intense, conditions are much less satisfactory and it is in such communities that development must cease and remedial action be taken.

The total area of artesian water bearing lands in this part of the state has decreased from 375 square miles to about 250. Everywhere except in the lowest most favorably located parts of the basins, individual artesian wells have decreased in yield. Without the artesian areas, a marked lowering of the water plane has been observed at many points. This may be slight in some localities, in others as much as 60 or 70 feet in the past four years is of record. These admitted conditions call for investigation. In order that we may shape our future policy intelligently it is essential that we understand the cause.

RAINFALL.

Naturally we appeal at first to the low rainfall of the past eleven years as the potent factor in this decline. The oldest rainfall records which we have in this part of the state are those which have been kept here in Los Angeles and at San Bernardino. The Los Angeles record extends through 27 winter seasons, exclusive of the present, which is not yet complete. The average for that time is 15.35 inches. The San Bernardino record covers 34 winter seasons, and the average there is 15.06 inches.

Expert meterologists tell us that a rainfall record which extends over a period of 35 years, gives us an average which is within 2 per cent. of the correct final average. For all practical purposes then this San Bernardino record may be accepted as the correct final average for that place, and as the precipitation for Los Angeles is substantially identical, conclusions reached from a study of the San Bernardino conditions will apply here. Furthermore, these cities have a rainfall less than that of the mountain areas and greater than that of the valleys at a greter distance from the base of the main ranges. They may be assumed therefore to represent practically the average conditions for this entire region.

It is of interest to note in the San Bernardino record that the average for the last eleven seasons, beginning with that of 1893-4 has been but 12.15 inches, nearly twenty per cent. less than the general average, while for the ten preceding seasons the average was 20.11 inches, or more than 33⅓ per cent. above the general average. The fact that the last decade has been one of low rainfall is very generally recognized, but it is not by any means so clearly understood that the preceding decade, with which the last is usually compared, was one of great excess. This decade included the phenomenal season of 1883-4 with a precipitation of 37.5 inches, 12 inches more than that of any other single season in the 34 years, and probably much the wettest winter in a half century. The dryest season in the record is that of 1898-9 with a rainfall of 7:49 inches, but half of the average, and the dryest group of three years was that ending with the winter of 1899-00, with an average of 8.12 inches. The average for the four seasons just preceding the present one is 13.8 inches, 8 per cent. less than the general average.

It is also perhaps not clearly understood that in countries of low rainfall there will be more seasons below the average than above it. The less the average rainfall, the greater this preponderance of dry seasons. With an average of fifteen inches as at San Bernardino, the preponderance is not great, there having been eighteen seasons below and sixteen above during the past thirty-four years. The Los Angeles record of 27 years includes 16 years below the average and 11 above. At San Diego, with an average of about 9.5 inches, there have been twenty-nine seasons below this average and twenty-five above it during the past fifty-four winters. This condition arises from the fact that where the rainfall is low, the occasional very wet winter gives an excess of precipitation equal to or even above the whole amount of the average, while there are no seasons with an equally great deficiency. So that more than one winter of minimum rainfall is required to balance a winter of maximum. To illustrate this: during the season of 1883-4, 37.51 inches fell at San Bernardino. The lowest winter of which we have record is that of 1898-9 with a rainfall of 7:49 inches. The first was 22.45 inches above the average, the other but 7.57 inches below, so that nearly three years of this minimum would have to be combined with one of the maximum to give the average. There cannot be a deficiency of more than 15.06 inches, while there is no limit mathematically to the excess.

DECLINE ONLY PARTLY DUE TO DROUGHT.

This examination of the rainfall records, substantiates fully the claim that we have just passed through a particularly dry period. Such a period is without doubt accountable for much of the shrinkage which has been observed. At the same time it complicates the problem of determing what the effect of the extensive development of the past decade has been. We have admitedly a falling water plane and shrinking artesian areas. Either of two forces, the drought and the development might have brought about this result. It is highly important to us to know to what extent each is responsible. In an attempt to reach a solution of this problem we have been greatly aided by observations carried out at a few points in Southern California.

Mr. Neff, at Anaheim, has kept systematic record at fluctuations of water plane there since Feb. 1898. The Gage Canal Co. of Riverside has kept a similar set of records upon one of their wells since 1892. Mr. Johnson at San Bernardino has observed for a shorter period, and others, here and there have made occasional measurements.

An examination of the profile constructed from Mr. Neff's measurements show that the decline in water level was steady and uninterrupted during the three very dry years which preceded and included the winter of 1899-1900. The succeeding winter was one in which the rainfall at Anaheim, at Los Angeles, and at San Bernardino, was somewhat in excess of the normal, the excess varying from 9 per cent. at Los Angeles to 28 per cent. at Anaheim.

During the early part of that season, the Anaheim profile shows a sharp rise in the water level, the gain during the first three months of the year being approximately two feet, but by the middle of the succeeding August the water had fallen again to a lower level than it had reached at any previous time.

In short, the decline continued during a winter of excessive rainfall. Throughout the season of 1901-02 the decline continued, but as again this was a winter of marked deficiency, a decline was to be expected, and is sufficiently acounted for by the low rainfall. But the season of 1902-1903 was again a winter of excess in precipitation. This excess at San Bernardino was about 15 per cent., at Anaheim about 70 per cent. and at Los Angeles about 22 per cent. above the average. The effect upon the Anaheim water level, while less marked than that of the heavy rainfall two years before, was more lasting; the rise of April and May, 1903, not being wholly lost until the first of January, 1904. Since that time there has been no heavy rainfall and the decline has been continuous until the beginning of the present season. On March 1st, this year, the waters had recovered 5 inches from the lowest point reached. The net loss since observations began 7 years ago is 27 feet 3 inches.

The important point in this comparison is the fact that the water level has continued to decline, or has barely held its own during two years of marked excess in precipitation. These facts seem to point unmistakably to over draughts upon the underground waters in the region to which they apply.

The results shown by the Gage Canal Co's measurements are similar in their general tenor. The well upon which they are conducting observations flowed in 1892. In June 1904 the water level was 38 feet below the surface. There were recoveries of 8 feet and 9 feet respectively during the seasons of 1900-1901 and 1902-1903, but these were lost in each case before the close of the succeeding dry season. The situation of the well near the bed of the Santa Ana river results in a prompt responsiveness on its part to floods and droughts.

Observations of this character indicate that drought alone will not not explain all of the observed shrinkage, although of course it has greatly increased it. In some of our localities at least we have reached the point where further development of underground waters should cease. This condition is not universal. In some communities favorably situated to benefit by the return waters from irrigation and where the underground supplies have not been extensively developed, there has been no decline in the ground waters even during the dry season through which we have just passed. In other localities less favorably situated, and subjecting their subterranean reservoirs to a severer tax, the conditions are much more serious, and in these it is imperative that protective measures be taken.

SUBTERRANEAN RESERVOIRS NOT INEXHAUSTIBLE.

In all cases it must be clearly understood that our subterranean waters are not inexhaustible. An underground reservoir may be drained just as any other reservoir may be. I have been told of a concrete case on a small scale which illustrates the condition well. In one of the smaller canyons tributary to Temecula Valley there was at one time a small but very regular spring near the lower margin of a not very extensive body of gravel. The water from this spring was piped to a nearby house, where it proved ample for domestic purposes. A little stream flowed down a tributary canyon above the gravel body and was absorbed by it. Its flow was variable, considerable in winter, amounting to but little in summer, but it sufficed to keep a portion of the small gravel mass saturated. During the period when the search for water above Corona was most keen, the spring was "developed." A tunnel was run into the gravel so that it drained more freely, and a pipe was run up the canyon, beyond the gravel mass, to the little stream which had discharged into it. With the increased flow from the "developed" spring, and the addition from the stream above, the owners of the property found their water sources "producing" about three or four times as much as before, a result of course to be expected from "scientific" (sic?) development. A few months later the tunnel dried out and the owners have since had to depend upon the variable flow from the stream. They are still no doubt wondering what was the matter with the spring, and attributing its failure to the dry years, not realizing that they had simply drained its source. This case is typical of much so-called water "development," the only difference being that the gravel storage reservoir here was small, so that the effects became manifest quickly.

Our illustration may perhaps be made still simpler. Suppose that a large tank has been slowly filled by water running into it through a 10-inch pipe, the pipe discharging constantly but seldom at its full capacity. When the tank is filled the excess water will spill over its edge at the lowest point. Then we have a condition which may be compared to that here in Southern California, before any of the water flowing from the mountain canyons had been appropriated; the tank representing the underground reservoirs, the supply pipe the mountain streams. Then suppose that we cut the 10-inch supply pipe above the tank and attach to it one six inches in diameter. This will divert all the water which would otherwise flow into the reservoir except during those rare periods when the larger pipe is running nearly full. We now have a condition corresponding to that when our surface streams had all been appropriated, except the flood waters. Still our tank remains full, the source of its waters but not its stored supply having been attacked. But now we begin to tap the tank in various places, drawing off small amounts of water here and there. Still its water level remains the same, the small draughts being less in total amount than that which still passes the six-inch diverting pipe and enters the tank through the 10-inch supply pipe. But as more and more holes are drilled all about the huge reservoir, which had seemed to hold too much ever to be depleted, the level of its waters gradually lowers, or perhaps rises spasmodically when the supply pipe discharges at its full capacity, but it soon loses these small gains and the general lowering continues until the tank is drained or until its water level drops below so many of the points at which it was tapped that drainage is no longer more rapid than replenishment through the occasional spasmodic supplies.

During this process we have a condition not unlike that existing in many of our underground reservoirs today. We are cutting off a great part of the source of our stored waters by diversions at canyon mouths, and at the same time attacking vigorously the accumulated supply. A large body of saturated gravels can no more be overdrawn in safety than a reservoir of the kind just described. The result in either case is depletion. The difference is in the time it takes to reach this result.

CARE MUST BE EXERCISED.

So, understanding that there is a possibility of overdeveloping; that a time may come for each community, as it seems already to have come for some communities, when to further tax the underground supplies is to deplete them, to expend principal as well as interest, understanding all these things clearly it behooves us as citizens interested in the welfare of our respective commonwealths to check expansion where danger exists, to move cautiously where we are nearing the safe limit of development, and in all cases to make constant observations which will serve as a definite guide in future expansion. Every well owner should measure the water level in his well each month. In a few years a body of data will accumulate which will be invaluable. The Survey has now about 100 observation wells scatered over this valley, but they are not enough and our measurements may be interrupted at any time by lack of appropriations. The individual owner can continue his indefinitely and by means of the data which they will furnish him he can determine whether the reservoir from which he draws his water supplies is being depleted or not.

Meanwhile, here as in all arid or semi-arid regions, economy must be practiced. With only one-fourth of our irrigable lands, irrigated, every drop which can be saved means more wealth, more beauty and more expansion for California. Flowing wells must be capped when not in use. Irrigation practice must be improved. Some communities are now using 1 miner's inch of water to nine or ten acres, others use the same amount upon only three or four acres, under similar soil conditions and with no better results. Evidently improvement is possible here. This subject: the possibilities of bettering forest conditions and of aiding in the direct absorption of flood waters by distributing systems will be discussed today by experts who have given the subjects much thought. All of these remedial methods tend to prevent waste and so are moves in the direction of betterment and increasing acreage. All should be heartily encouraged and earnestly supported by every one who has the best interest of this garden spot of the world at heart, and the list includes not only every resident of Southern California, but all of the thousands of our eastern friends, whose privilege it has been to enjoy with us our climatic and scenic charms, and share with us for a time our heritage of beautiful homes.

Chairman Cook—I take great pleasure in introducing Mr. F. E. Trask of Los Angeles who has prepared a paper on

PREVENTION OF WINTER RUN-OFF.

The great problem of Southern California today is water supply; a subject to which the majority of residents give but a passing thought. A stranger arrives, and after looking about a few days, buys an orange grove or a home, with the assurance that there is ample water, and he is satisfied.

To those who handle the subject from any standpoint, whether as irrigators or promoters, and, more particularly, those who have had in hand the distribution, development and delivery of water, this question presents a different phase, demanding the greatest efforts for a solution.

Prior to 1870, all demands were supplied by surface water from near-by springs and canyons. True, some attention had been given to irrigation. The Mexicans and Indians had constructed short earthen ditches and diverted stream flows and watered their garden truck and a few trees, and the question of a sufficient supply of water at that time was not an issue.

About 1870, the development at Riverside began; and the systematic and scientific diversion and application of surface water dates from about this period. Following in rapid succession, other sections of Southern California began to divert and to utilize all available surface supplies, and in from 12 to 15 years all known sources had been appropriated. The continued inrush of settlers, desirous of acquiring homes, created a demand for additional water, which compelled most communities to take up some line of water development. In its first stages, this consisted principally of the location of artesian sources and the exploiting of them through the medium of bored wells; and, later, through the driving of tunnels. The high returns from the use of water upon Southern California soil further stimulated a desire for additional water, which, coupled with the greatly reduced rainfall, created a condition in which there was an insufficient supply for these growing demands. As the artesian wells and tunnels became reduced in output the demand for water became so great that pumping plants were installed and these artesion wells were thereby further exhausted. Wells were sunk in tunnels and pumping plants installed therein and the water level generally lowered throughout the country.

This insatiate demand for water was followed by a most thorough prospecting of large areas, developing the fact that the valleys throughout Southern California in most cases were underlaid by vast reservoirs.

The dry years continuing, the rainfall supplying only a part of the needs of the sections already developed and demanding water, additional pumping plants were installed from year to year, with the result that we now find the ground waters throughout Southern California have been depleted to an alarming extent. Much litigation has resulted from this scramble for water; and if the Supreme Court had not come to the rescue with its decision defining the rights and privileges of owners of water-bearing ground relative to the reasonable use of such waters, it would be a matter of but a few years when there must have necessarily resulted a complete destruction of some of these sources upon which the draft has been greatest.

It is well that the indiscriminate extraction of these ground waters has been restricted to a reasonable use; and the writer's judgment leads to the conclusion that the resources are sufficient to maintain all developments to date, and in certain sections to inaugurate additional developments with reasonable assurance of permanency. While all this depletion of underground reservoirs has been going on, very little, if any, attention has been given to their re-charging or replenishing.

In 1892 and '93, the writer and an engineering friend were engaged in the study of one of the canon watersheds of Southern California, making surveys and preparing data for use in threatened litigation at which time the subject of restricting or of the retarding the winter run-off from said canon became to us an important feature, demanding more than passing consideration. In the canyon large and extended beds of gravel existed, the stream covering but a small per cent of the surface, over which it passed with little percolation loss, owing to the silted and impervious nature of the channel. The conclusion we arrived at was that it would be great economy, supplying our clients with additional water, should they expend a moderate sum each year in spreading the storm and flood waters over these large bodies of gravel, which under natural conditions received very little water in storage. From time to time thereafter, as opportunity presented itself, the writer put into practice, in a moderate way, this idea of artificial charging of gravels within the canyons and the debris cones at mouths of canyons, The encouraging results were such that at the suggestion of clients, the writer contributed to the Rural Californian for June 1903 a paper entitled "Water Conservation in Southern California." The sole object in this paper was to draw the attention of water consumers throughout Southern California to the great benefits resulting from the artificial saturation of the gravel beds lying above the elevation of the irrigated sections. The subject created much interest and the supply of the paper was soon exhausted, the writer printing a re-issue, for which there has been a considerable demand, especially by those having in hand the management and the supply of water for the different colonies and towns of Southern California.

The solution suggested in detail in the above paper was as follows:

"That the winter and storm discharge of the many rivers and streams of Southern California be diverted at the mouths of canyons upon the debris cones of said canyons; that these waters be not allowed to run in the present channels, but that they be diverted from place to place over the porous sands, gravel and rock surface, to the end that all water may be absorbed by the debris cones: that districts be established for each of these water sheds, that the organization of each district be effected by uniting corporations and persons interested in maintaining the supply of underground water and beneficiaries of the proposed work, and that each organization maintain a force of laborers at all times sufficient in number to divert and to dissipate all waters not used directly for irrigation, with the possible exception of extreme floods, which should be kept in the natural channels.

"In general terms the works should be a diversion dam, located near the mouth of the canyon, at such a point that the water could be led out upon any and all of the open and porous gravel and rock forming the great mass of the debris cone. This dam should be constructed with a full knowledge of the necessity of passing the maximum floods down the old natural channel. In some places it might be a temporary structure that would give way to dangerous floods, while in others a more permanent construction would be advisable.

"The main diversion conduit should be a wooden flume or pipe, in sections suitable for rapid dismemberment, re-location and reassemblance. In most cases a few hundred feet would be quite sufficient. The discharge should be split up into small streams and spread out fan-shape over the debris cone, with a constant shifting of the streams, to the end that these small channels may not be silted up and made impervious. Some locations might require the digging of ditches and building of dams along the contour lines and at right angles to the surface drainage grades, to intercept and to redistribute any collected water resulting from the saturation and silting up of the gravel beds lying above the ditch or dam."

To fully understand what this system of artificial recharging of debric cones in gravel beds signifies to the material welfare and progress of Southern California, it is worth while to analyze existing conditions briefly. Today we are diverting at the mouths of the cañons of Southern California all available normal surface water and passing same through pipes or cemented ditches and canals down to the land to be irrigated or the homes to be supplied. In doing this we have practically eliminated the factor of seepage. In other words, the only water that can be used to recharge debris cones and gravel beds must be the rain and flood waters which are in such large volume as to be beyond the needs and capacities of the diversion systems and works at the mouths of the cañons.

Second. We have through the agency of tunnels, wells and pumping plants been drawing an increasing amount of water from these same gravel beds from which we have cut off the normal supply. In other words, if we are to maintain the saturation of these underground reservoirs we must do so with the flood waters. What have we done towards aiding nature in replenishing these gravel beds? With one or two exceptions where moderate efforts are being made to this end, there is absolute inaction by those in whose hands the large interests of our water companies are placed.

What would we think of the business sagacity of a man who fell heir to a moderate amount of money which was placed for him in a bank, and as soon as he acquired the right, began to pay out that cash indiscriminately and persistently, making no provision for replenishing his account? And yet, this is precisely what we are doing as regards our underground water supply. The heavy rains of the present season have aroused considerable interest in this subject, and those who have ordinarily given but little thought to the question recognize the necessity for saving some of the vast volume of flood waters which they see passing down the axis of the valley and on to the ocean, the great percentage of which floods are of no material benefit. It certainly is time that united efforts be exercised to control, to conserve and to utilize this water. The problem is not a difficult one; and if the case of every cañon supply in Southern California can be solved, its solution will give to water consumers the cheapest water they will obtain from this time on.

The first problem to be considered is the method of diversion. The point of diversion should be for the debris cones as near the mouths of the canon as possible, since the higher the point the water is turned into the gravel the larger the volume of material lying above the zone of consumption or use, and, consequently, the larger the volume of water that will be accumulated at an elevation, from which to draw economically. In large cañons, like the San Gabriel and Santa Ana, expensive diverting weirs should be constructed. They should be of a permanent and enduring nature, and so designed that floods of such magnitude as to have an element of danger in their volume, may be allowed to pass down the natural channel. Gates should be so arranged that when the intensity of the flood has subsided below the danger point the waters can be controlled in whole.

In the smaller cañons, it may be found best to construct temporary diverting weirs and at times of excessive floods to allow the same to be destroyed. Each cañon will require special study and special treatment. The conditions controlling should be worked out with due consideration for all interests, and no hasty and ill advised interference with torrential floods should be tolerated.

From the diverting weir, the water should be spread out and made to cover as large an area as possible. This is highly important, because the capacity of the gravel beds to consume these flood waters is in direct proportion to the areas covered or flooded. The first step requires the use of either pipes or flumes, diverting the water from the natural channel out upon the banks adjacent and at such points that it will not return. The writer believes that in nearly every instance this can best be done by the use of a few hundred feet of light steel pipe constructed in such a manner that it can be taken apart and removed from place to place, should circumstances require it.

On the larger debris cones, the writer would advise trenching along contour lines, the material from the trenches to be thrown on the lower side of the trench; and at the intersection of drainage gulches and old flood channels, he would build a loose rock-filled dam of such magnitude as to stop and to divert along the ditch any flow that might pass down said channel. These ditches might be constructed from 500 to 1000 feet apart, and the water allowed to fill them and flow over at such times as the supply was more than the gravel in and above the ditches would consume. Under this condition we would have a series of ditches, one lying below the other, the upper ditch catching the water first and the ground under its influence taking as much of the water as possible, the balance passing on to the next, seriatim, until the whole supply disappeared within the gravel mass.

The surface run-off in cañons may be materially increased during the summer months when water is most needed for irrigation, if those interested will pursue the same method of saturating the gravel beds lying outside of the influence of the surface stream, at different points throughout the cañon and above the point of diverting the surface water.

The method of diversion would be similar to that on debris cones; and in most cases a few hundred feet of pipe laid into the stream through a temporary boulder and gravel dam, would answer all practical purposes. When the necessary diversion weirs, ditches and dams have been constructed the maintenance expense should be nominal, it being necessary to keep laborers on the work only at such times as flood waters obtain. The writer has found by his own experience that four or five men during the maximum periods of cañon discharge will handle a considerable volume of water, the essential requirement being their presence on the ground ready promptly to meet and to control any condition that may arise.

In conclusion, the writer wishes to impress upon the water managers of Southern California the necessity of immediate action looking to the refilling of the gravel beds from which they have been pumping excessively the past two or three years. Much has been said and written about the depletion of these underground reservoirs; while the writer's solution stands as the only remedy yet offered, looking to the restoration of these gravels. Nature will do much to replenish them when our seasonal rainfall again passes above the average for a series of years; but if you are to continue in the benefits that are yours, you must aid nature in this work. At no time in the history of Southern California has there been a question of more vital importance than this nor one to which Southern California will owe more of its material permanency and progress; and the money spent in the systematic distribution of the water over the debris cones and gravel beds will aid in not only maintaining the supply of the necessary fluid, but, in the writer's judgment, if prosecuted energetically, will result in again raising the water level, thereby materially reducing the pumping lift and cost of pumping operations, from year to year. Further; the limit of reclamation and development of arid lands here has been reached, with a few exceptions, if the systematic recharging of the gravel beds is not consummated. A co-ordinate factor with flood conservatism, in the water problem, is the subject of the capping of wells and the bulkheading of tunnels. In some sections attention is paid to this matter, but in many nothing whatever is done to restrain the discharge from artesian wells and tunnels during that period of the year when water is not required; and large volumes are allowed to run to waste for from three to six months each year. If those people who own the artesian wells on the lower levels and along the coast have no need of the water, they should be compelled to close said wells; and the supply at points many miles distant would be improved thereby.

Chairman Cook introduced Mr. Wm. Mulholland, Supt. L. A. City Water Works, who read a paper on

WATER WASTE.

I was invited by your Program Committee to read a paper before this meeting on the subject of Water Waste, and I must say in advance that the selection of a water works manager for an expression of opinion on this subject in so far as it relates to municipal supplies may not prove a wise one as such persons are apt to be in a chronic state of irritation with regard to such a matter, and hence more or less unfit for its frank discussion.

Should it be therefore found that this brief paper degenerates into nothing more than a querulous and scolding lecture, I plead in advance for your kind forbearance, and stipulate that you may apply your own interpretation to the facts herein presented and deal with the conclusions as in your judgment they may deserve.

From a perusal of the subjects listed for discussion at this meeting and the names of the gentlemen assigned to handle them, I am led to assume that it will be unnecessary for me to comment on or offer any suggestions for the conservation of the occasional copious runoffs of storm water that in the present state of our water storing and distributing facilities are unavoidable, although without doubt such lost water may in a sense be regarded as waste. This matter I am certain will have able elucidation at the hands of men who have made a special study of it and are better qualified to suggest means for its amendment.

Inasmuch as the recent great development and extension of the agricultural industries of Southern California coincident with an unusual diminution of the water supply has brought forth among our farming brethren in a marked degree the innate engineering ingenuity that is a notable attribute of the American people, who were thus enabled to meet the exigencies that required them to devise hasty and in many cases highly efficient methods of procuring water to save their crops and orchards, I believe it would be somewhat presumptuous for me to attempt to lecture them on its economical application and use. We may, I believe confidently intrust this phase of the subject to the man who pays the bills as it is not likely that a farmer whose water costs him anywhere from 2 to 3 cents per thousand gallons is going to waste much of it.

Twenty or thirty years ago one might have been justified in this country in inveighing against the wasteful methods in vogue in the use of water for irrigation; but those were the days of the struggling stream and the open weedy and neglected earth ditch, now happily an institution of the past, and it seems that about the only flagrant practice remaining to be corrected is the one of permitting the unbridled perpetual flow of artesian wells in such districts fortunate enough to still possess artesian water.

The perfection of Southern California climate coupled with the great fertility of her soil, naturally awakens and fosters a desire even in the most materialistic of her inhabitants to follow Palmerston's suggestion to "tickle the ground with a hoe and see it smile with a crop'" and this spirit is so universal that we find even close into the hearts of our busy towns scarcely a habitation, be it ever so lowly, but in it some attempt is made to beautify it by the cultivation of a few flowers or a patch of grass. It is to this esthetic spirit much of the attraction of this country is due and however we may pride ourselves on the abundance and profit of our agricultural and horticultural products, candor still compels us to admit that the tourists, lured here by such attraction, must ever be considered as a valuable contributor to our income and adjunct to our prosperity.

This being the case we must not stint the most important element to this beautification, water; and this brings me to the subject on which I believe it was the intention I should address you, namely the use and waste of water in municipalities.

Careful perusal of water works reports and engineering journals leads one to the conviction that on an average fully one half of the water flowing in the mains of unmetered cities in the United States is wasted. This conclusion is well supported by statistics from many cities that have changed from the absurd method of furnishing water to their inhabitants by assessed rates or guess (which amounts to the same thing), to the rational plan of measuring how much is used and collecting for it.

Every gallon of water devoted to the domestic and other uses of our town in Southern California reduces by that much the amount available for irrigation purposes in the surrounding country, and as the prosperity of our towns is largely if not wholly dependent on the development of the country, it devolves as a duty on the water works officials of those towns to see that no water is wasted. This duty is not secondary to the one of reducing waste with a view to reducing the cost of distribution of the wasted amount which is in itself an important consideration.

The City of Los Angeles with an estimated population of 175,000 last summer, consumed, or more properly speaking consumed and wasted an average of 34,000,000 gallons of water per day, or at a rate of about 195 gallons per capita.

In the summer of 1901, the portion of the city supplied by the Los Angeles City Water Co., drew water from the mains at the astounding rate of 300 gallons per capita.

In February, 1902, the city took possession of the works, and the case being urgent on account of the rapidly diminishing water supply the Water Commission at once set itself to the work of checking the suicidal practice of permitting the water taker to help himself to what he wanted and waste as much as he pleased. Inspectors were appointed and the city divided into districts with men assigned to patrol them making house to house inspections, and serving notices to owners to have whatever leaky plumbing found repaired forthwith. Now there is no delusion on the part of the average citizen who gives thought at all to water works matters, more deep rooted than the one that work of this character will prove effective in stopping waste. Every summer when the injunction goes forth warning people to be economical in the use of water, the papers are full of letters from well meaning citizens to whom the idea has occurred for the first time, advocating the appointment of men for house to house inspection, but it is a well known fact to all water works managers that money expended for this purpose might just as well be thrown in the sewer for any good it accomplishes. The principal cause for the failure of this system is not far to seek nor difficult of explanation. There is a degree of sacredness about one's home that generates resentment against all strangers who for any purpose intrude it. This resentment is much intensified if such intrusion is for the purpose of anything that has the appearance of espionage. Even with the best tempered people it becomes a repugnant task to the Inspector to demand admission to the most private portions of the citizen's home, so that in a short time the man lapses into an indifferent and reluctant worker, performing his duty in a perfunctory manner if at all. To add to his difficulties he has to be most circumspect in speech and manner to prevent his being charged with rudeness or discourtesy in the discharge of his duty. Complaints of this kind became so frequent at the office that investigation of all of them was out of the question, and such as were investigated could result in nothing conclusive as there were generally no witnesses to the act complained of other than the complainant and the Inspector.

A not uncommon suggestion is that the Water Department employ plumbers to go around from house to house to keep the fixtures in repair. As there are at present over 41,000 services in use in this city, it may be imagined the expense this would entail besides the many actions for damages that would arise from failure or faulty plumbing that would certainly be charged to delinquency of some of the Department's men.

In an experience extending over a period of nearly twenty years, I have never yet found a man who would frankly admit that he had been wasting water, no matter how complete the evidence was against him. I have known of men to plead guilty of horse stealing or many other forms of theft when caught with the goods, but have known of men who deliberately connected pipes with those of their neighbors who were bona fide water takers, and surreptitiously use water for many years without the Department's knowledge and without paying for it, and yet deny any guilty intent.

After a complete demonstration of the futility of personal inspection it was decided to meter the services of those whom it was assumed were the heaviest consumers and were hence in all probability, in the then state of our knowledge, the most profligate wasters. These were thought to be the ones with large and highly improved grounds, and the Commissioners were at once assailed for adopting such a measure, not for the reason that any of them admitted he was using more than his flat rate would allow him, but on some other inexplicable ground that implied that the vegetation would perish should it be definitely known how much water it required.

Delegations appeared before the Board making piteous and pathetic appeals for a continuance of the flat rates. Many of the suppliants declared they would sell out and leave the country or let the grass die, or put into execution some other plan most dire and dreadful, but the evil work went on notwithstanding, and revealed what our old friend Ko-Ko would no doubt have declared "a state of things."

Careful measurements were made of the grounds of these consumers and calculations made to determine the depth of water in inches per month that was used on them as shown by the meter readings. These depths ranged all the way from 3 to 16 inches showing that there existed a radical difference of opinion among the owners or caretakers of these grounds, as to how much water their vegetation required for its proper nourishment. It will need no argument to convince anyone familiar with the cultivation of grass or plants that even half of the larger quantity or the equivalent of 8 inches per month of rainfall is entirely beyond the reasonable needs of anything likely to be grown for ornamental purposes, but the evidence was made complete by the ocular fact that the lawns and shrubs of the most economical users were quite as vigorous and thrifty as those of the most lavish. Some of the lawns we found to be in an absolutely sodden state, the grass showing by its feeble thin spears the effect of the soppy condition of the soil.

Within a month or two the bills began to diminish and the many complaints about lack of pressure in the mains in the districts metered became fewer until ultimately the people themselves became so reconciled to the meter that many of them now declare they prefer it to the old method of charging, and indeed some of them have substantial reason for their change of view in the reduction of their bills when taken for the year round.

I have said that "in the then state of our knowledge" we thought these cultivators of semi-aquatic gardens were the principal culprits in the matter of waste, and the qualification was made advisedly for we soon found out that "there were others" that needed our attention.

Careful half hourly gaugings were made of the discharge from the sewers and it was found that the minimum flow was between the hours of 3 and 4 A. M., and was 800 inches. It was clear that 90 per cent at least of this must be due to leaky fixtures and reckless waste for it represented what must have gone into the sewers between 1 and 2 A. M. when household duties are suspended.

The draft from our reservoirs observed at the same time showed that there was no time during the whole night when the outflow was less than at the rate of 10 million gallons in 24 hours. Surely, this nocturnal use could be accounted for in no other way than by the grossest waste.

Close inspection of the business blocks, most of which were accessible without the difficulties usually encountered in private dwellings, revealed a condition of almost criminal waste through perpetually running closets and leaky fixtures that no amount of persuasion short of the actual shutting off of the supply could prevail on the owners or tenants to have repaired. Computation of the water used in a few of the large blocks that had been supplied through meters for periods long enough to give fair data as to what the whole business section of the city should consume seemed to show that about 2 million gallons per day would be ample, while as a matter of fact it was taking about 4½ million gallons per day to supply it, so it was resolved to at once proceed to meter this whole section. The promptness with which this action resulted in hurry calls for the plumber was a pleasing revelation. It is true a few of the more politically influential ones appealed to their Councilmen or the Mayor or the deputy chairman of some political body or other to have the darned thing removed, but they found it necessary at least to have recourse to the plumber as affording the most certain means of relief. It was notable also that the outfall sewer that had been overtaxed to the danger point for a year or two, was amply able to carry the burden it had been groaning under.

You will ask, no doubt, "Has the saving in water justified the expense of the meters?" I reply by asking the question: If the quantity of water saved, spared the city from the appalling effects of a temporary water famine, how shall we appraise the benefits? But as a matter of fact the meters have not cost the city a dollar for the reason that until the first bill was presented nine out of ten of the consumers had got so in the habit of wasting water by disregarding what appeared trivial leaks, permitted water enough to waste to pay for the meter and all the expense of setting it, and in some cases twice as much, for we found several instances where a flat rate of say 4 or 5 dollars per month had been paid, that the meter bill for the first month would be 50 dollars or more. Of course, there were loud and vigorous protests that the meter must be wrong, and other excuses enough to render life a burden to the Collectors, but no compromises were made, the slogan of the office being "stop the waste or pay for it," until now the people find they are on an average paying less than they did under the flat rate system and the city is ahead on this small district alone about 2 hundred inches of water.

At the present time the Department is setting meters at the rate of about 300 a month, and the public, in whose interest they are set, has begun to accept them with equanimity and as a matter of course.

It is curious to look back and review the unreasonable opposition their introduction invoked when the fact was so widely published that unless some restrictive measures were taken the city would have suffered a water shortage that would certainly have worked incalculable injury. But that has been the history of this innovation in every city where the system has been introduced, and as with us, the result of the use of meters after a fair trial has been so manifest that the public has come to regard them as a necessity as much as fire hydrants or any other water works fixture.

But it must be remembered that the reason for their adoption was far more vital in Los Angeles than in almost any other city in America. Take such cities as Cleveland or Milwaukee, the two most universally metered of the large cities of the United States; surely, it was not a scarcity of water that impelled them to curtail waste by this means, for they take their water supply from the great lakes that lap their shores, and the pipe through which they distribute it costs them 30 per cent. less than it does Los Angeles.

The fact is that waste of water in this city threatened to sap our very vitals, and our efforts to curb it have already been rewarded by a reduction of nearly 40 per cent. in the consumption, which gives us several years respite to procure an additional supply. So all hail to the little silent watchman that never sleeps and that can neither be bribed, bullied or bluffed.

If it appears to you, gentlemen, that I have been overriding this hobby, and I admit it is a hobby of mine, for the riding of which I have suffered much execration, I shall let its results be my apology, for it has added to the available water supply of the City of Los Angeles and the country generally by at least 500 inches of water already and will double this amount within a year.

AFTERNOON SESSION.

At the opening of the afternoon session, the chairman introduced Mr. James Mills of Riverside, who spoke as follows on:

ECONOMY IN IRRIGATION.

Professor Cook has met me in the large orchards of the Arlington Heights Fruit Co., over which I have the pleasure to preside as superintendent of the Land Department, and he has heard me speak on the ground, and I believe that if I had you in the orchards at Arlington Heights I might well be able to illustrate the methods we pursue there looking to economy in irrigation. I have no paper. I am not, a writer. I am merely a farmer; and farmers work, but write little. I will tell you as well as I can of the methods pursued in this matter on Arlington Heights, and I will be as brief as possible, because there will follow me a man with splendid ability in addressing audiences of this kind—a practical man and one who has succeeded.

Let me say in opening that I believe from actual experience that there are more orchards ruined by over-irrigation than by under-irrigation; that there are more men who ruin their prospects by pouring water on and off their lands than there are those who do it by irrigating their lands.

As I understand irrigation, it is placing water in the soil for the development of the orchard, for the taking up in solution of the elements of the fertilizers that you put in or that nature's God put in the soil and feeding it through the root system to the tree and thus depositing in the laboratory of the tree the foodstuffs that were taken up and carried through nature's avenues to their place of deposit.

Now, the theory I would like to give you, is this, that if you pour water over your soil you are damaging your soil, damaging your prospects and damaging your bank account. I will tell you what we have done and what we have accomplished; and I will begin with one piece of land, sandy and somewhat sterile, which has had but one irrigation each year for the last three years, and that irrigation given in order to plant the cover crop.

When I took possession of the office I am no occupying under Mr. W. J. Fraser, who is manager of that great property, I found this block of twenty acres took more water than we could possibly afford to give it. I gave it six hundred inches of water the first irrigation. I came to the conclusion that if it needed that water each irrigation, we didn't want the land in our business, because it was a great loss and a great failure. I dug into the soil ten feet, everywhere, through the twenty-acre tract. I took the soil to my home and put it under the microscope, and I found that I had building stones in miniature and not soil. All of the humus had been burned out or washed out or eaten out—it was gone. I saw that I must first place in the soil humus.

I took animal fertilizers to start with, and on top of them I put my cover crop of cow-peas; following that with a cover crop of the Canadian field peas, the common white field peas. I turned them under in the winter. I caught and held the rains, and I pledge my word that I hadn't to irrigate that piece of land until the first of October the following fall. I did not leave it without carefully examining the soil every month. I had dug a hole ten feet deep, six feet long, sometimes longer, and 18 inches wide, that I might get in there and examine the soil as to the content of moisture in it. I also took those samples of soil to my office and examined them there. I watched the trees. There is the index—the tree. The tree will tell you when it needs water, and there is no necessity to give it before then, because you will damage its prospects if you do. I watched that every month, and prohibited the irrigators from putting the water on until the first of October. It was a re-budded orchard that had been Sweets. It was budded over to Navels. The buds were three years old. We took forty-five hundred loose boxes off that place with its one irrigation; and it didn't need the irrigation at that time, but the peas did, because I wanted to put another cover crop in.

The next year we irrigated it in July to give it another cover crop, and we took ten thousand boxes of fruit off it. I give you this illustration that the pouring of water onto that piece of ground every thirty days would not have been economy; it would have been a dead loss. I say to you, for the sake of economy in irrigation, don't irrigate your tree until you know it needs the irrigation.

Water should not leave your soil. You can irrigate your soil without wasting water. There are thousands who will tell you that you can, for they have seen it done; they do it themselves.

We irrigate one piece of land not oftener than eight weeks, very seldom within nine and ten weeks, in the hottest time of the year. Right alongside of it, right across the line, within ten feet of that orchard, there is another orchard irrigated every thirty days; and within ten days after every irrigation it is needing another drink, and needs it badly. Why? On these lands over which I preside, we cultivate, and cultivate, and cultivate. We get that dust mulch that holds down the water. The other man does not cultivate. He scratches the top of the soil the way many of you do,—many of you, for I have been over your lands all through the state. You scratch the top of the soil. What happens? Every capillary tube that you ought to have shattered and deld down with your dust blanket is in contact with the surface of the soil and the greatest power in earth or Heaven, outside of the Almighty Himself, the great sun, that reigns over the meridian draws every drop of water that you put into the soil out again and evaporates it into the atmosphere, whereas, every drop of it should have gone into your root system, up through your tree, into your leaf, and there, by transpiration, sent off into the atmosphere. Why put water into the soil if you are going to allow the sun, with its tremendous power, to suck it up and send it off into the atmosphere? I tell you, gentlemen, that you have got to use your cultivator. It is water, it is fertilizer, it is fruit, it is success; and without the cultivator, it is failure. (Applause.)

I say to you, gentlemen, that you don't need to use one inch to five acres on any tree or any orchard that is not 12 or 15 years old. Take your young trees. You plant a young orchard. A fine piece of soil, friable, capable of the very finest results if you use your plow and your cover crops. You put it in. You spread your water through five or six furrows, shallow, and you run the water through them. What good does it do that tree? Not a whit. Now, if, in placing that young tree, you would dig your hole deep and put it in, you don't need more than one furrow during the first two years of its life, and you will be giving it a root system down deep into the earth so that it can in its after years hold its head up heavenward, because it has its roots down towards the center of the earth. You ought to get a root system three or four feet down. You can get it. You can get it deep, for I have followed my roots six or seven feet down. And there is fertilizer there; there is humus there; and there is a vast reservoir of sub-soil moisture that will sustain you and your tree in the years of drought such as we have had the last few years. For economy of water, then, I say to you, in planting your trees strike their roots deep; keep your water near it. The very best orchardists do this. Not up against it, because that would spoil your tree, but 18 inches or so from it, so you can cultivate it with a walking cultivator, and let it sink down into the soil.

That will strike out laterally and will give the tree ample room to spread its roots. Don't have your tree spread its roots all over the surface so that they are within ten or twelve inches and when you come to plow you will cut its roots off. The roots have no right to be on the surface. They ought to be where, if you plow nine inches, you will not cut your leading, feeding roots. Three years ago I dug into a piece of land, a heavy soil. I could not get down 18 inches. It was as dry as the hub of that old cart out there. The next year I went down I got six feet; last year I got down 12 feet. I cut me a trench 16 feet long, 12 feet deep, and drove a trench underneath the tree. Those roots three years ago were on the surface. We cut them out unmercifully with a disc plow; left nothing that a plow could catch; went down and down and down; and those places which needed irrigation every three weeks before only need it now every eight or nine or ten weeks apart.

We can get along with less than one inch to five acres, and we can actually get along with less than that for years to come, especially where we have any young orchard. I have found this—that the fewer times I irrigate, the better it is for the tree, the better it is for the company, the better it is for our bank account. I say to you, that the less water, in reason, you give your orchard, the better. Give it the cultivator. Where you used to irrigate twice and cultivate once, cultivate six times, if you have got the time, but get that mulch that holds the water down and feeds it to the tree. Don't let it be sucked up to the surface and be deposited in the atmosphere where it is no good to you or to the tree.

How shall you get it down deep? Get a deep furrow into your soil; not a surface furrow, but a deep furrow, and as few as possible.

A Delegate—How deep?

Mr. Mills—Nine, ten inches. Ride on your cultivator. Load it down. Get it down. When you irrigate, don't run the water off your soil. At the lower end, get your cross-furrows, and when your water comes down there, take care of it. Strike it out into your cross-furrows; hold it there. If you have more water than your men can handle, go up to the flume and cut it down. Cut it down, whether you are entitled to it or not. Let it go back into the ditch and flow down that ditch to your neighbor, who needs it worse than you do if it is running off your land.

Now, that you have got your land irrigated, close your furrows quickly. Don't leave it 24, 36 or 48 hours, until you can get your cultivator in upon it. Close them at once. A July sun will take 35 per cent. of the water that you put in the soil out in one day. Close your furrow and get your ground mulched, and it will cut off the water from going off by evaporation. Just as soon, then, as the water has equalized itself in the soil—and it will equalize itself all over if you will hold it—get in and cultivate. If two horses can't do it put four on, and if four can't do it put six on. And put your cultivator down eight or nine inches, and hold it down. Cultivate across, cultivate with the water, and cultivate again. Every time you cultivate you mellow the soil; you let the air in; it brings the oxygen; it feeds the nitrifying bacteria and increases them, and as they increase just in that proportion does your tree get fertilizer, and it will not without it. The cultivator will economize in fertilizer, the cultivator will economize in water; the cultivator will economize in money; it will save your money and pile it up for you. (Applause.)

A Delegate—How close to the trees would you run these deep furrows?

Mr. Mills—How close to the outer margin of the tree, do you mean?

The Delegate—Yes, sir.

Mr. Mills—We were using four, five and six furrows. We talked it over, the foreman and myself. On one piece of land I said to him, "Drive a trench across there the whole twenty feet." I went in and examined it. We had used four furrows. It is a double set place.

The next irrigation, I said, "Jim, use two furrows. Drive me another trench in another place." Lo, and behold, we had just as much water distributed all through the soil with two furrows as with four. We went to the other lands where we were using six furrows. The sun delights in that as the devil delights in getting hold of a poor poker player, sometimes. Now, we went in there and made four furrows, and we did it with the other lands that we took care of. Why, I want to tell you that we have found that where we use four instead of six we have cut the sun's little bit of job off fifty per cent.

A Delegate—How long do you let the water run in those furrows?

Mr. Mills—We let it run two, three, four days, sometimes. We run a very small ripple. We don't run a full head. We believe that the water circulates under the ground as well as above it; that it will equalize itself in the poorest soil; that the capillary tubes do not run vertically only, but run laterally everywhere. They say we get too much near the ditch and too little at the lower end. We find our trees at the bottom now doing just as well as the trees at the top. But formerly I found this: I found some places, the trees at the lower end of the orchard were rich and luxuriant, and there was fruit on them, but yonder there was nothing on them. Why? I could not figure it out for the life of me. I rode the plow, I followed the cultivator, I talked with the men, I watched the irrigator and all. But after three or four months I came to this conclusion; the lands were hard and unyielding; they were just set up like adobe bricks. They were adobe bricks; if you had just cut them out in sections you could have built a house with them. And why? The cultivating had been done poorly. I said to one man who was there formerly, "How did you put your fertilizer on? Didn't you do it broadcast?"

I could not plow it, I could not cultivate it. And I came to the conclusion deliberately that the fertilizer had been put onto the top of the soil and that the irrigating water that formerly run off slushed it off, and some of it got into the lower sections. Now, you have no right to wash your fertilizer out that way. Put it in your soil. Bring your water slowly to it, so that as it gets towards the end of the furrow it is seeking the depths and when you have reached the end of the furrow you know that your soil is saturated for the time. If you put a furrow out six feet from your root system the water will strike the root system if your work has been done on the surface properly so that it can get through the plow sole. Don't have a plow sole. Put your furrows deep; put your cultivator deep; get your furrows for irrigating deeper than your cultivator can go, and you will have no plow sole to worry you. We use our sub-soiler. Where four horses didn't do it, six did or eight did. But we tore them up. We don't do it any more; we don't need to do it. Lands that needed irrigation on Arlington Heights every three weeks—the lemons—don't get it now; they don't need it.

You are no rancher if you don't know what is under your soil—whether it is hard-pan, or sand, or gravel, or rich loam. Get down into the soil and know what is there and then you will know what to do, know what it will hold. It needs, of course, three or four hundred pounds of water to make a solid pound of material; but some of you use six, nine and twelve hundred pounds of water to do that. Don't do it any longer.

A Delegate—How do you cultivate under the tree?

Mr. Mills—I don't do it. I keep away from the tree. Don't injure the tree. The roots go out everywhere. The water goes down. You don't need to get up under your tree. We don't prune our trees up; we let them lie down upon the ground We get the most and the best of our fruit on the ground.

A Delegate—How far would your water spread sidewise in a light sedimentary soil, say, within three feet of the top?

Mr. Mills—Under those conditions I will say that we have found out—where we have our trees planted twenty feet apart we have used two furrows.

The Chairman—Perhaps it would be fairer to out next speaker if we should go to the next subject on the program, and then after we have that, again take up the questions.

The Chairman—I have been up in the Arlington orchard and I have been delighted, because they do what they say they do. It is a mulch down not two or three inches but five or six inches. Now, a few years ago I said to a gentleman,' 'How is it your brother has got this fine reputation for product in fruit?" He said, "It is because of the excellent management in the orchard." So, when I read Professor Powell's report and saw that of that fruit only four per cent. was injured, I believe, I said to my wife, "That is the Chapman orchard." I am glad Mr. Chapman is here today, because he uses a deep mulch and he uses the least amount of water, I think, required. It is my pleasure to introduce

C. C. CHAPMAN. OF FULLERTON.

You all know how refreshing it is to listen to a good talker as well as a good rancher like Mr. Mills, and you are all very glad that he didn't have a paper to hold him down to any particular line. You get an inspiration from hearing men talk as he does. And it is not theory, either. He runs his business up at Arlington just the same way, and if you would go up there once and visit, as I have had the pleasure of doing, you would come away feeling you had never known anything about ranching before, but you had learned a great deal that particular day. Every time I visit that section I come home determined to do my business in a better way. I always learn a great deal from Mr. Mills, as we all have this afternoon. It is almost useless for me to attempt to discuss the question that he has so ably handled. I just want to emphasize a few of the points that he has made.

In the first place, about the numerous and shallow furrows that are generally in use. I want to say that my experience is that of Mr. Mills. It is fatal to the very best results and the greatest economy in the use of water. You do not need six furrows. I have never reduced it to two, as he has done, but you had far better reduce it to four if your trees are twenty-four feet apart. But, instead of making the ordinary three-inch shallow furrow, as most ranchers do, go down and use a machine something like a sub-soiler. Now, I have had great difficulty in finding a machine that would do this work—a furrower that would require four big animals to pull through the orchard. I have at last succeeded in getting one. I use the point of a sub-soiler with a very large shovel, and we take four of those and go down about twelve inches. Then what have you done? You have put the water down nearer where you want it; you have saved this tremendous loss by evaporation, and these scientific gentlemen tell us that in these narrow furrows that it runs from seventy to eighty per cent. of loss in a summer day by evaporation alone. You have not only saved in the loss by evaporation, but you have put the water where it will do you some good. And, as he said, it is out

Another thought I want to emphasize is not only this thing of the
of the way of the sun's rays. So, try that.
furrow, that the too frequent irrigation. I am just as sure as he is that that is a mistake. It is a mistake to water your ranch every thirty days or every forty days or every sixty days. Now, you will think you cannot help it, it must have it. Well, of course, when you do that, you all understand, you are only watering the surface, you are only watering twelve or fifteen inches. You are hurrying the water over it, and that is all you have done and, of course, you have to get at it again. You have attracted the tree to come up with its little feeders to the surface, and, of course, just as soon as the sun's rays come out the ground is heated, eavporation takes place, and you have to irrigate again. But that is a useless waste of water, it is a waste of labor.

And I want to tell you something else it will do. Your orchard is more liable to grow dry by that process, get dry, and the result will be puffy fruit. Don't depend on water to grow your fruit. Some of you put on a good deal of water, but I want to tell you I don't believe you can raise a good orange in a lake of water. I would emphasize what Mr. Mills has said with reference to cultivation. If you want to raise a delicious orange, don't raise it on water. Your flavor will not compare with that gotten by cultivation. If you want an orange that will carry to market, when it requires fifteen to forty days to reach a market, don't raise that orange on water; raise it on cultivation. Save your water, save your trouble, and, as Mr. Mills says, let your neighbor have it if he needs it. You don't need it. Of course, there are conditions in soil that must always be accounted for, and yet I believe that Mr. Mills has in his large place of hundreds of acres, almost every kind of soil, and I know I have several kinds ranging from the lightest, loamy, sandy soil to a very heavy soil. It is a mistake to use too much water.

But, now, you must adopt drastic measures if you attempt to undo the work that you have for years been doing—teaching your trees bad habits. You must do as most people do when they are cutting off bad habits. It requires a good deal of will-power and a good deal of nerve. You have to teach your trees to go deep. Put the water there first; don't put it on the surface.

Now, I remember some trees I was fortunate enough to purchase from Mr. Mills. I put them out in June. We watered them, of course, at that time; and we watered them in September following. We didn't put a drop of water on those trees until the next June; and in two years they had two irrigations, and I will defy any man to produce finer trees in Southern California. They are eight to ten feet high now, and not three years old. But I taught them, as he said, right at the start to go down after water, and then if I don't irrigate them any particular day, week or month, there is no particular damage done, don't you see, because the roots are down out of the way.

Now, just another thought about the running of water onto your neighbor. I tell you that is not only wasteful, but it is almost criminal. If you are enterprising, you won't run the water in the public highway. You are wasting the very life of your soil by doing so, and then, too, you are making a lake out of the highway. If, instead of running your furrows clear down, you will form up your last two or three rows of trees nicely, they will hold all the water that should come to those trees. Give attention to this important question of irrigation. Mr. Mills does it. He wants to become acquainted with his soil, and that is what we must do. Let us follow the splendid example he has set and we will all feel amply repaid for having the pleasure of listening to him this afternoon. There is a great deal that might be said, but I know the Chairman has a happy faculty of drawing out all that an audience knows; and you have a great deal of information here this afternoon before you, Professor, and I will let you take charge of it. (Applaus.e)

The Chairman—These gentlemen are good teachers. Would you like to ask any questions of them? I doubt if we have any better teachers anywhere than they. I have been in both their orchards and I know.

A Delegate—How deep is the water on Mr. Mills' orchards before the rains?

Mr. Mills—How far down in the ground?

The Chairman—How deep are your orchards moist before the rains come?

Mr. Mills—We prospected our soils during July and August. We went always ten feet, and sometimes fifteen—once fifteen. We didn't get to the botom of our sub-soil moisture. We have followed this practice every year, to satisfy ourselves that we had the moisture in the soil.

A Delegate—Mr. Chapman used one expression that I would like to inquire about. He said "form your lower trees up." Does he mean basins, and, if so, does he prefer that to Mr. Mills' method of cross-furrowing?

Mr. Chapman—I think it would be more easy.

The Chairman—You have tried the furrows of Mr. Mills?

Mr. Chapman—Yes, sir.

The Chairman—And prefer the basins?

Mr. Chapman—Yes, sir.

A Delegate—How far do you run that water in the 20-acre piece? What length do you run your water on the 20-acre piece, that sandy piece of land?

Mr. Mills—Just the 660 feet. On this other piece which Mr. Chapman examined with Mr. C. C. Teague and others, we were running about 1200 feet. This year we set out some young orchards and we are running the water 1200 feet.

A Delegate—Don't you think that necessarily carries a great deal of the vegetable matter and substance in the soil down to the lower part of the orchard?

Mr. Mills—No, we don't run our water that way. We run a very small head of water. In fact, you could go to any of our irrigating furrows at the flume and take the smallest point of your sharpened pencil and shut the gate down with it. In fact, that pencil would not go through the aperture that we use for irrigating. We have the sub-soil full of moisture. We haven't got to wet it down to China. We have merely got to reach the sub-soil water, and our irrigating furrow is furnished by a very small stream.

A Delegate—My experience is that that small stream would take a long time to get through an orchard.

Mr. Mills—Well, it does. It depends upon the fall in the ground. Of course, on the sandy piece, that 20-acre piece, that is not true. When we irrigate that, once a year, we do it with a larger flow. It is almost level, and quite a sandy piece. It has to have a bigger flow. But the water gets down there. No hard-pan ever gets there, and it goes in. We only do that once a year to put our cover-crop on.

A Delegate—I would like to ask Mr. Mills if he has any adobe soil?

Mr. Mills—Yes, sir.

A Delegate—Do you treat that the same way?

Mr. Mills—This piece I speak of having prospected twelve feet down, three years ago we were not able with a pickax to get down eighteen inches. My foreman and myself tried it. We sweat well over it. We gave it up, because there was no moisture under that. It was a very hard, heavy piece of soil; and that is the very piece we went twelve feet down and had our moisture this year. We gave it a heavy coating of animal fertilizer two years and a half ago; we followed it with a cover crop last year, and another this year. We have got the humus in that soil, and the soil is much more mellow.

The Chairman—Is there any relation between your cover crop and your moisture? Does that add to your moisture?

Mr. Mills—Wonderfully, wonderfully. Cover-crops are our salvation, gentlemen. It will advance the water-bearing—water-holding capacity of your soil enormously. And it will give you fertilizer. You read that Century article in last May—last September. Get it, if you didn't. It is worth a hundred dollars to anyone of you. I wrote to Professor Moore, who sent all these little microbes through the country recently, about it, and asked him if it was true. I had already sent him samples of nodules, which he said were magnificent. I said, "Is it true, Professor Moore, that a good cover-crop is worth thirty to forty dollars an acre in fertilizer?" He said, "Yes, it is true." I believe it is, and I am going to act on it. I take it for granted that it is. We don't need to take it for granted. It will retain the water; it will enrich your soil, it will make it mellow and capable of the very finest pulverization. That is what we are after. Get your peas, put in your cover crop; grow it by all means.

A Delegate—What time of the year do you plant?

Mr. Mills—This year I will put cow peas in one orchard in May, June and July; put one section in at a time; leave one section to irrigate. Follow with field peas August, September and October. This year I put in a crop of cow peas and planted on top of it a crop of field peas. We have an enormous crop; we are delighted, because I think we have got $40,000 of value in it. The peas have saved our lands from washing; they help us hold the moisture, they give us fertilizer. They till the soil, because the root goes down and puverizes the soil, and as they go down the air and water follow, your soil becomes aerated; you don't need to plow it then. The cover-crop is wealth, it is success. It will fill Brother Braly's bank to overflowing with orange money if you will just use it.

A Delegate—When do you plow this under?

Mr. Mills—This year we have to plow them under as we can.

A Delegate—Are you plowing now?

Mr. Mills—We are plowing now and trying hard to get them under; but it is hard to put 1200 acres in in a day. We have 1200 acres of beautiful cover-crop; some of them ten feet high—actually ten feet high. I took my fork and lifted one away up yonder to a gentleman the other day, and he was amazed, and so was I.

A Delegate—Do you do that every year?

Mr. Mills—Every year. You need not be afraid of giving soil indigestion in this country with cover-crops. Put them in. You will save cultivator, save water, save in the purchase of fertilizer; you will save every way.

Mr. Braly—One suggestion would come in very pertinently about this irrigation business which has not been mentioned, and that is winter irrigation. I will illustrate. In 1884, I was in Fresno, at the beginning of the raisin industry in Fresno. One gentleman planted a raisin vineyard of about a hundred acres. He was hard-headed, a little bit, and he said he was going to pursue a method. He planted root vines, well selected, and he had his land checked. It was very dry to begin with. Now, that country is all well sub-irrigated. He said that the last rain that came, he tried to get the storm water into the ditches, the rich water. He planted in January. In February and March he filled these checks with water and refilled them. When they would go clear down and out of sight, he would re-fill those checks with water. He would continue to do that until—I think it was about the last of March. For two months he continued to do that. Then he started in with his cultivators, and he never put another drop of water on that raisin vineyard that year. When a little crust would form under his cultivator teeth he would go deeper; and finding or getting no cultivators that would do the work satisfactorily there, he sent down to Los Angeles and found a chisel-toothed cultivator that would go six or eight inches if it was pressed down. And he had good teams and he kept going down. And this gentleman would go with his spade and see whether there was any crust forming; whether the cultivator teeth were riding on a formation. When there was no crust forming, then he was satisfied. But he kept that vineyard cultivated, and cultivated, and cultivated, all summer until he had the finest growth of vines of any man in the country and made the finest success of his vineyard.

The second year he irrigated his vineyard again in February, when there was a little flood. He took advantage of the winter, rich flood waters, that is, from the arroyo's that would come down and fill the ditches. The Kings river water, which is a clear, beautiful water, was shut off during the winter time, and that gentleman never irrigated his vineyard. That was the dry time. That was the beginning. The waterlevel was from fifty to seventy feet below the surface at that time, But he stored the water in the winter time, and then with his cultivators he kept it mulched, so as to have no capillary possibility of that moisture from below getting up. Well, that vineyard was the best vineyard, made the finest record of any vineyard in Fresno County.

The Chairman then introduced Mr. J. E. Adamson, of Pomona, who read the following paper:

POWER AND PUMPING.

The history of pumping in Southern California is a story of continual change, both in conditions, and apparatus. The former being the result of the efforts of Nature, to strike a balance in the matter of supply and demand.

The change in apparatus, being necessitated by the change of condition and the unpreparedness of the machinery people, in the matter of pumps of moderate capacity, and high efficiency.

There have been developed in the past decade, two general types of pumps (the centrifugal and the deep-well), having good average efficiency even in the smaller sizes. I speak advisedly when the word developed is used, as, though both these pumps were in use, and had been for several years, they were most deplorable examples of "cut and try" engineering.

Many of the bad mechanical features have been eliminated, through a process of wholesale experiment, carried on by the manufacturers, at the expense of the water using public.

Both these pumps now show good results, when the right conditions are present, but there is the rub.

No two pumping propositions have the same conditions even when located in the same immediate field, and with all the costly experiment and improvement, there seems to be a great void in the matter if reliable data, from which the prospective owner may select the right pump for the right place.

The same might be said of motive power. The larger plants have an advantage in that highly developed steam apparatus can be used, the leading features of which are more generally known, and results more easily demonstrated, than is the case with the Gas Engine, the motive power most adaptable to the needs of the small user, unless he is in a position to use Electric power.

The increasing depth to water, year after year, brings with it fresh problems, more and more difficult of solution, and carrying the question of water development further and further into the realm of the Engineer and away from the non-technical owner.

As in almost all aspects of the water question, the larger companies have the advantage of the small owner, in the matter of engineering.

Their operations being on so large a scale as to warrant the employment of competent engineers, something the small company, and the private owner, cannot afford to do.

This can be helped by co-operative organization, which if carried out under careful management, would benefit not only the small owner but to a considerable extent the present large owner, and save much good money to the water interests every year, in fuel economy and depreciation of machinery, to say nothing of the more economical purchase and installation of apparatus, under the advice and supervision of engineers whose business it would be to study the problems, and their solution.

There is at present a movement on foot in Pomona, for such an organization, to cover the production of 2000 or more inches of water, from widely distributed wells. The effort being along the line of a large central electric plant, distributing power to the stockholders and others, for all purposes.

This company would be in a position to employ high grade engineers to care for the engineering work of its stockholders, from the strictly power plant work, to the hydraulic engineering of the water development.

Such a company would have sufficient control of its stockholders' interests, that the very best results could be attained, at minimum expense by the exchange of apparatus, unsuitable in one case, to a place where the conditions were found to be right.

Such a centralization of power has been made on a moderate scale by the Temescal Water Co., with results that confirm the belief that there is a considerable saving in the cost of motive power, over the present detached system, of individual effort.

We believe the water using public of our community can save much of the cost of pumping, the only question being the raising of the necessary capital, which should be as far as possible, from among the interested parties, so as to eliminate the speculative element.

The present low price of distillate oils, has a tendency to offset the advantages to be expected, and therefore makes it the harder to interest the people in their own welfare.

As a matter of fact an organization on these lines would be of immense advantage to the participators, even if the power plant element were impracticable, the results to be attained from the engineering end of it being worth much effort, besides the strong element of control that would be felt in contracting for supplies or power.

On the face of it a proposition to compete with the gas engine having a high thermal effciency, by the use of the steam engine with electric transmission of power, and the attendant lossees, would seem to be foolish, but when the items of comparative depreciation, and interest on investment, together with wages which form so large an item in the operating expenses of the small plant, are considered, the balance will be found on the side of the electric proposition, even at the present law price of fuel.

There may be instances where the necessary power in electrical form may be purchased from the companies who have promoted the use of the mountain water powers, at a less rate than it can be produced by steam. But here again will come in the benefits of organization, in the making of large contracts, at minimum rates.

One thing is certain. When a large amount of the power sold is generated by steam, there is good business in the location of the generating plant reasonably near the field of use, thereby avoiding the heavy losses in long distance transmission.

To sum up the power and pumping proposition, there is much to be saved by co-operation and the elimination of the small unit, not to mention the advantages of a wider use of electric lighting in the outlying districts, with the profits coming back to the user. But even if we stick to the small unit and the gas engine, there is still much to be gained by mutualization of our interests for better, and more uniform engineering.

In the matter of apparatus, there would seem to be no doubt that much good would be wrought, if the manufacturers could have the counsel of reputable engineers, in touch with the needs of the water producers, and the short comings of the various pumps and engines, to the end considerable would be added to the general average efficiency.

Mr. Geo. J. Mitchell, of Pomona, made an address, taking for his topic:

FORESTRY IN RELATION TO WATER.

For twenty years the mountains which form the water-sheds to the north of us have been my companions and friends. Years ago I began a crusade in favor of better forest conditions, but was silenced by the argument that I was doing more harm than good; was lowering the value of realty; that nature was sure to come to our rescue and even things up; a few wet winters would fill the subterranean reservoirs and all would be well. It was said that I placed entirely too much stress upon the value of forests on the mountains as affecting rainfall. The wet winters did not come, reservoirs did not fill up; we have insulted nature, and broken her laws, and she is going to let us help ourselves awhile. I made no mistake as to value of forests and their influence for good. No words too strong in which to state their value to the community.

In order to make my remarks of any value we must concede that forest masses have a strong and well defined influence upon rainfall. There is an undercurrent of dissent to this statement, but you will find it is originated and circulated by the lumbermen; the men who are destroying our forests with superhuman energy. Scientists will occasionally be found arguing that leaves of trees expire moisture, hence trees are of little value as rain inducers. Be not for a moment misled by false prophets. In spite of expiring moisture forest masses especially on elevations, do induce railfall. and conversely the destruction of forests is followed by drought and finally desert conditions.

Let us study conditions not theories. The land of Canaan—including The Holy Land—is situated in the same latitude as Southern California, and in many respects is marvelously like Southern California. Canaan is the promised land of the Bible. A moist land, a land of rivers, and springs, a land flowing with milk and honey. The tribes of Israel on taking possession of this land, flourished mightily. The best portion of Canaan, like California on the Pacific, lay along the Mediterranean in a strip averaging 100 miles in breadth; to the north bounded by the mountains of Lebanon. These mountains were covered to their summits with magnificent forests. The land was hilly and generally forested. and streams and springs were numerous. The scriptures cover the ground by calling it a "good" land. Magnificent cities sprung up, Tyre, Sidon and a host of others. This was the land of the Phoenicians with their world trade, and great colonizing activity. There were more large cities the size of Los Angeles and up in this favored land, and more inhabitants per square mile than any other land on earth. Not so large as our state, Canaan had in the reign of Solomon over 10,000,000 inhabitants. The land, like our own California, was subject to dry years, but they were separated by long intervals and but little harm ensued. The Sidonians were great lumbermen and opened up a large export trade in lumber, just exactly as we have done. As their great forests of cedar were removed those dry years increased in frequency and the droughts were more prolonged. Their lumbering entirely with the axe was slow and it took many centuries before the danger point was reached. Even down to the first century of our era it was considered a fertile land. Agriculture was declining and the desert was rapidly encroaching on the cultivated lands. The forests had been nearly all removed and the rainfall became light and irregular. Agriculture now rapidly declined. The coast-wise cities lost their trade, the interior cities were in many cases deserted. The dry years now predominated. The beds of streams that had flowed for centuries became dry ways. Springs and wells dried up and the country, following its agriculture, was ruined. I have ridden over this land from end to end and a more disheartening journey I never took, It is a desert land filled, literally filled, with the ruins of stately cities and magnificent temples. Jerusalem and Damascus are now the principal cities. The former is said to shelter 40,000 souls and the latter 20,000 or 30,000. There is not the slightest sign of prosperity about either and they are simply wretched, dirty holes, where no decent person would care to live. There is not in all that land another town worthy the name of city as we understand it. Most of the inhabitants live in wretched mud villages and their total number is not probably 5 per cent. of their once great population. In all the land no forest tree is to be found. When I was there no rain had fallen for 32 months. Is there no lesson for us in the fate which has come upon this ruined land? It will be urged that it took many centuries to bring that land to its ultmate ruin, and that Americans have occupied this country but some 50 years. True I grant you, but the ways of the Sidonians with their slow methods of lumbering were not our ways. One of the first authorities says, "We have cut more lumber and destroyed more forest growth in the 19th century than all Europe and Asia Minor did in 30 centuries." It is a tremendous statement, but investigation proves it true. A close calculation, conducted under government auspices, reveals the fact that in 55 years there will, at present rate of destruction, be no forest trees in the United States. So you see we have bridged the centuries that it took the ancients to reach the danger point and as the French say: "We have arrived." For that same danger point is close aboard, right ahead and do not make any mistake about that. The lumbermen, I mean the men who own and run the saw mills and logging outfits and who control and direct the destruction of our magnificient forests, have been and are the worst enemies the white race has known since America was settled. Always destroying never building up. Their methods of treating all forests which they attack have been criminally wasteful from start to finish. We should meddle with no man's business. The forests they destroy, I am reminded by the lumber butcher, are their property and they can do as they please with their own. Right here is where I want your closest attention, your best interest, for here is the crux of the whole situation. The business of lumbering is a peculiar one and, most unfortunately, this business does affect the welfare of every man, woman and child in the community. No other business engaged in by man bears any similar relation to society. This lumberman's business is and of necessity must be everybody's business. The American people have never realized this fact. Claiming to be the most progressive of all peoples, we are in this matter of forestry very far behind all the highly civilized nations of the earth. About every nation and state in Europe protects its forests. The lumberman cannot work his own sweet will on the forests to the detriment of the whole community. The unrestricted ownership of forest trees is denied. Many states own large forest areas and the tendency is to increase this ownership. In all Europe lumbering is carried on scientificially and under government control. The lumberman is told by a forest expert just what trees he may cut, and provision must be made for new growth of trees as old ones are removed. About all the government owned forests are run at a good profit and are continually improving in condition. We must educate our people in forestry up to the European level. We must no longer be barbarians. The unrestricted ownership and destruction of forests as practiced in this country is simply barbarism. The principle is just this: No man or body of men has a right to destroy a forest, no provision being made for new growth, when such destruction works a hardship on or menaces the welfare of the whole community. This is a matter for state legislation. It is of such paramount importance that if necessary the state constitution must be amended. However, I think that a strong forestry law which will be constitutional can be enacted. Such a law should without any delay be enacted. Every acre of our remaining forests should be at once placed under state protection, and timber cutting only allowed under rules of scientific forestry. This is simply a measure of self preservation and the state should protect itself. The measure I recommend is radical, but the situation more than justifies it. It should have been adopted 40 years ago, and our glorious forests saved for our children and their descendants. No finer, grander forests were to be found on earth than those of California when first she became a state. No such reckless, wasteful lumbering was ever done on earth as was done here. Our magnificent redwoods, the like of which cannot be found in the world, are a good deal more than half gone. Nearly the whole remaining area of these trees is owned by non-resident syndicates. Twenty more years of such lumbering as we have seen in the past will just about deforest this state. The people who now own our forests are alien to the state and care not one whit whether California sinks or swims. Is it not time to call a halt? Are we not justified in calling good and loud?

Forest fires have run a good second to the lumberman and have done much in the way of destruction. In spite of all the silly things said about the mysterious origin of forest fires, rubbing together of dead branches, phosphorescent stumps, spontaneous combustion, etc., you can safely take my word for it, that there are no self originated forest fires, and that allowing for accidents, 98 per cent. of our forest fires are preventable. In Europe so careful are they of their forests that they have practically no forest fires. Our proposed forestry law would not be complete without provisions to prevent forest fires. With a stringent law, honestly enforced, forest fires would practically cease.

Of all the places I know, none is more in need of active forestry work than Southern California and none has less of it. Our people on this subject seem to be affected with a deathly lethargy. In the Northern part of the state, with much less need than we, much greater interest in forestry is shown and felt. There they can pursue horticulture without irrigation, as they have a greater rainfall, while with us horticulture means irrigation. For years we have watched our water supply diminishing and, though the way was pointed to us, we have scarce turned a hand over to help matters. I am speaikng of the horticulturists of Southern California. We have been waiting for the government to help us. We forget that in a republic like ours, the government never takes the initiative, it waits the move of the people. The true word is—Help yourself and the government will help you.

Forest Reserves:—No benefit up to date. Forest fires are less in number because there is nothing left to burn. Could not in many places light a fire if you tried. Reserve has just been placed under new and better management. Under Head Forester Pinchot, I hope and believe the Reserve will be cared for and reforested. We must, in season and out of sason, never forget to urge and insist that the government pursues a liberal policy toward the Reserves.

We have lost during the last 12 years some 5.5 to 6 inches of annual rainfall. I ascribe all this loss to crude and wasteful lumbering and forest fires. The average of our rainfall was about 17 inches, for the last 12 years about 12 inches. The loss seems to be in the rains which we may call local; which affect this coast only. These rains it seems are about lost. In the denudation of our mountain sides unfortunately our loss is many fold. The loss in actual rainfall is a heavy one, but we lose also in the unrestrained run-off. The absence of restraining root systems of the trees on our mountains allows the rain, which formerly percolated slowly through the soil until it reached the under ground reservoirs, to go to waste. Hence these reservoirs heavily depleted by pumping in the summer are not replenished in the winter and show a shrinkage in area of over 35 per cent. These figures come from Prof. Mendenhall, but are exactly confirmed by experience. The wells from which my own supply for irrigation comes were at the surface 12 years ago, and today are down from 90 to 100 feet. Our next loss is by evaporation caused by loss of forest cover. This causes springs and streams which used to be nearly constant in flow to diminish and dry up entirely during the late summer.

Another loss, which always makes itself felt when the soil of mountain areas is left bare, is that of erosion. Sun, wind and rain work together to dry out and wash out the fertile elements of the soil until it becomes absolutely barren. This is a very present danger and must be looked to without delay. The only remedy is to replant. I have outlined the forestry situation by just touching on the salient points. No man living can do justice to the subject in 30 minutes.

Now for the remedies as I see them. Have amendment to Constitution, or law as may be thought best, denying unrestricted ownership of forest trees in this state. Also Forestry law caring for and protecting forests in this state, with very stringent provisions as to fires. Re-forest our mountain sides, State and counties, to help the U. S. Covernment. Work under direction of Pinchot with T. P. Lukens as first lieutenant. I have not gone into subject of reforesting as Mr. Lukens, far abler and better posted than I, will tell you about it. But my great reliance is upon this same reforesting. I believe thoroughly carried out it will be our salvation. Persuade Mr. Pinchot to close the reserve to everybody for at least 5 years so that young trees planted may have a chance. Especially keep out all cattle and sheep, all campers, picnickers and fishermen, a resommendation to this end from Los Angeles Chamber of Commerce will have much weight.

Encourage in every way the planting of two or three varieties of Eucalyptus on all vacant lands in our foot hills. They will do splendidly up to 2000 and even 2500 feet. Don't require good soil and but little water. A little care for two years and they will take care of themselves. A tract of foot hill land not worth more than $5 or $10 per acre planted to red and blue gum will commence to pay at 6 years and thereafter yield a net interest of 20 per cent. on a valuation of $50 to $75 per acre.

Let all who possibly can, take part in this. Individuals, syndicates, corporations, land and water companies; and it would be a good investment for Railroads. Treated by proper rules of forestry these foot hill plantings would be practically everlasting, better after 30 years than they were at 10.

Agitate to have lumber and manufacturers of lumber especially wood pulp put on free list. The greatest good for greatest number should rule, and to protect these forest butchers while they lumber us out of house and home is nothing short of national lunacy.

But gentleman we have in horticulture reached the limit. Depending on pumping as ⅞ of the acreage now does for irrigating water, we cannot go on for another decade as we have for the decade just past. If nothing is done to better conditons as they now exist, if our strange lethargy still holds us in its grip, in less than 15 years horticulture in Southern California will be practically a thing of the past.

Ask the Southern California Section of National Irrigation Association to help us again as they have done before in this forestry matter. Ask them to take the lead, and to appoint a strong committee on Forestry and Water, said committee to get similar committees appointed by every board of trade and chamber of commerce in Southern California and then working all together and keeping everlastingly at it, so agitable the matter that the remedial measures suggested above may become accomplished facts, and the body of the people intelligently interested once for all in forestry. The results will be such as to delight everybody and our beloved Southland will bloom and prosper as never before.

WHY REFOREST THE MOUNTAINS.

Forests should be maintained on mountain slopes, because the rain fall is greatest on such slopes. Not only do trees induce precipitation, but in the spungy stratum of decaying vegetable remnants, they retain far more humidity than even cultivated soil. They with avidity reabsorb the surplus of moisture from the air, and refresh by a never-wanting dew all vegetation in their vicinity. Forest trees by the powerful penetration of their roots, decompose the rocks, and force unceasingly from deep strata the elements of mineral nutrition to the surface. They create and maintain the sources for the gentle flow of water-courses.

Von Muler says, forests, as ready conductors of electricity, influence and attract the current of the vapors, or impede the elastic flow of the air, with its storms and its humidity, far above the actual heighth of the trees, and condense the moisture of the clouds by lowering the temperature of the atmosphere. Forests shelter the soil from solar heat, and produce coolness through radiation from the endlessly multiplied surfaces of their leaves.

The island of St. Helena when discovered in 1502, was well forested. The introduction of goats and other causes led to the removal of the forests. Heavy floods and severe drouth were the result. Replanting of the forest trees towards the close of 1700 resulted in a more uniform rainfall, and its better distribution. Subsequent destruction of the forests have again brought back the former condition.

When the island of Ascension was discovered in 1815 it was barren, and so destitute of water that supplies were brought from the main land. The effects of planting trees resulted in an annual increase of rainfall from 10 to 25 inches in a few years. It now grows 42 kinds of trees where but one grew before.

In our own San Bernardino mountains a careful study of the influence of forests on rain-fall and run-off, shows in every instance one-third greater precipitation on forested accreas than on deforested areas, although contiguous and of the same general topography. And while from the forested areas there was a constant flow through the summer months, the flow from the deforested areas ceased altogether early in the summer, having run off in destructive floods during and immediately succeeding precipitation.

Hutchings points to the unmistakable degeneration of man following the destruction of forests. Men reared in forests are stronger than in non-forested regions. Again Von Muler says, "The destruction of forests has often become to the country where this has happened, a real calamity and a speedy cause of approaching decline and ruin."

"But there is another and more cheering era in this history. This is when civilization has advanced and man sets about restoring the desolated forests."

In France and Germany it has been estimated that at least one-fifth of the land should be planted with forest trees in order to maintain the proper equilibrium for successful farming. In California but four and one-half per cent. of the area is forested. In Southern Caliqrnia alone, less than two per cent is forested.

Then the forest is a thing of beauty and affords a shelter for the wild creatures that God has created. The forests were created for all people for all time. Man has recklessly, through greed and indifference, robbed future generations of their heritage. We are amenable to the laws of God as we are to the laws framed by man, many of which we would violate, if it were not for fear of punishment by penalties prescribed. For this reason we should reforest the mountains, for as a race and a people we will surely be held responsible by posterity and our God for the destruction of that which was never ours; only given us to use, and deliver to our successors unimpaired.

One thoughtful observer and forceful writer, after many years in the mountains noted, after a long season of drouth, the gathering of church people to pray for rain. She said to them, "better you go to the mountains and plant more trees."

Our honored President of the United States says, "the prosperity of California in the hotter and dryer agricultural regions depends upon the preservation of her water supply. And the water supply cannot be preserved unless the forests are preserved."

There are many reasons why we should reforest. It must be evident to all thoughtful observers that Southern California has reached its limit of development, unless more water can be obtained. That can be accomplished only by planting trees on our water sheds for the conservation of the rainfall.

The Chairman—This important subject is now before you.

Mr. C. C. Chapman—I never heard the question so forcefully put before as the Lieutenant has given it to us this afternoon, and I am sure we all feel, as we have felt for a long time, that this is a great question for us to agitate. It takes a good deal of agitation to inspire and enthuse the American people on any subject; but when once we are afire with it, then our Congressmen must look out. And we ought to make that an issue. The only difficulty is that in Southern California, while we have hundreds and hundreds of thousands of acres of good land, we only have two Congressmen, and they are a very small matter with such a body as Congress. But we have a Senator and two Congressmen, and I am sure they will do our bidding, and they are able men, and if we can just let them know that this is what we want, the farmers and business men as well, then they will be able to find perhaps some other elements in the northern section of the middle west who are as deeply interested in this question as we are.

A Delegate—I am a member of this Association, but not in this state. I live in Kansas, and I have been taking a great deal of interest in forestry and the planting and cultivating of timber for fifty years or more. Many of our farmers take hold and put ten, twenty or forty acres or sixty or a hundred. I put out a hundred in ornamental trees and forest trees, and have cut 200,000 feet of lumber out of my own planting, and found it a profitable matter. And I still keep up the grove by planting to fill up for what is taken out. Everyone ought to follow the rule to plant two trees where he cuts one. If that rule were enforced our country would have a wider basis for its prosperity.

The Chairman—Mr. W. Scott Way, of Pasadena, has some resolutions.

Resolutions introduced as follows:

Whereas, It is proven beyond dispute that a large proportion of mountain fires are started upon forest reserves by the carelessness of hunters; and,

Whereas, The admission on permit of irresponsible and indifferent persons for the purpose of hunting game upon the reserves must be a continual menace to the preservation of the mountain water sheds; therefore, be it,

Resolved, That the Water Congress of Southern California, assembled at Los Angeles, March 13, 1905, most heartily approves of the proposition as recommended by Forest Supervisor Thomas, to make the San Gabriel Reservation a game preserve, from which all hunters may be excluded.

Resolved, That we believe that without such exclusion from the forest reserves, all effort to prevent mountain fires therein will be in great measure arduous, expensive and ineffective.

Resolved, That a copy of these resolutions be sent to Supervisor Thomas for transmission to the Forest Service Division at Washington.

Upon motion the resolutions were unanimously adopted.

Mr. Robinson—Those resolutions are first-rate as far as they go But they do not, I believe, cover the ground fully. As has been pointed out to you in the paper by Captain Mitchell this afternoon, there is great damage constantly being done to our forest reserves by the passage of sheep and cattle over them. I do not wish to inveigh against the sheep or cattle men, but I must say , from personal observation throughout California, Utah, Colorado, Wyoming, New Mexico and Arizona, that in the passage of a band of sheep over a reserve they cut, nibble, nibble to the root, and what they do not nibble to the root they dig out with their hoofs, break the roots and absolutely destroy the vegetation. The sheep are much worse than the steers. I believe that the passage of bands of sheep and cattle across the reserves ought to be prohibited absolutely. There are many thousands of sheep and cattle which are now being pastured on the reserves. I would move, therefore, that this Water Congress ask the Department of Agriculture to absolutely prohibit the pasturing or the passage of sheep and cattle over our forest reserves, and I here offer the following resolutions:

Moved—That it is the sense of this Water Congress, assembled in Los Angeles on March 13, 1905, that the passage over and the pasturage in the forest reserves, of cattle and sheep, is highly detrimental to the forest growths of these reserves, and the United States Department of Agriculture is hereby requested in the interest of forest preservation to absolutely prohibit such passage over and pasturage in the forest reserves of all sheep and cattle.

Resolution seconded.

Mr. Mitchell—I have had frequent occasion to call the attention of audiences that I was addressing to the subject of grazing rights. Even the President, clearminded and right-thinking as he is, by reason of his residence in the West and his experience among the cowboys, got a little bit shakey on the subject of grazing rights. The grazing right does not exist. No man on public land has a right to put any animal there that does any harm to any other man. Our cattle barons were pasture thieves. It was taken so much as a matter of course that they gradually got the people into the idea that because a man owned a certain number of head of cattle he had a right to graze them on the public domain. We must get that out of our heads. Have no respect at all for the cattle man. If he wants to graze his cattle, let him show up, as we do, his land to graze them on. If the sheep man wants to pasture his sheep, and not be a thief, let him get pasture for his sheep or get rid of them. It will not hurt this country. Don't be alarmed in the least. The cattle industry will prosper just the same and even do better. Let us deny once and for all, and educate all who come under our influence, up to the idea that there is no such thing as grazing rights in this country. We need not have the least fear of doing wrong to any man when we ask that all cattle and all sheep shall be excluded from the reserve. (Applause.)

The resolution was adopted without dissent.

Mr. Trask—An engineer deals in facts, and he frequently rubs up against conditions which certainly appeal to him. I am glad to see the interest taken here today in this forestry question, and I heartily endorse every word that has been said about the preservation of our forests, and I hope that the matter will be followed up with energy and that something will be accomplished. As has been said, it takes effort, and united effort, to accomplish anything along this line. I had a chance in 1900 to make water measurements, make comparative water measurements, from two of the watersheds of Southern California. Sometime in 1899 a forest fire burned off probably fifty per cent. of the Cucamonga watershed, and in the spring of 1900, or late in the season—I think it was in May, if my recollection is correct—we had some quite heavy rains, and I measured the flood runoff of the Cucamonga canyon and of the San Antonio canyon, which are canyons lying side by side, although one is considerably larger than the other, and I found that the maximum flood runoff of the Cucamonga canyon, over which the fire had raged the previous season, was fifteen times as great per square mile as in the San Antonio watershed, which had not been damaged by the fire. Now, that is a cold fact. There might have been some little difference in precipitation in the two canyons, but they were adjacent and the storm was quite a general one, and the only conclusion to draw was that the fire had created a condition which gathered the water, or caused the mountains to gather the water into a torrent and pass it out of the canyon at once, whereas, in the San Antonio canyon, where the fire had done no destructive work, the water was in great measure retained and went into the ground and was used later in the season when it was worth something to the orchardists.

Mr. Lorbeer—We don't want to stop right here. Let us strike while the iron is hot. The forest reserves have been transferred from the Department of the Interior to the Agricultural Department. Now is our time to strike as hard as we can. This matter of keeping out hunters and keeping out sheep and cattle, is well enough; but something must be done to more efficiently protect the forests from the fires and we ought to embody it in these resolutions. Furthermore, we ought to make as strong a demand as possible upon the Department of Agriculture to make some special effort to at least try the experiment of reforesting the mountains. No one can examine the California rainfall charts without feeling that the mountains and the forests upon them affect these local rainfalls, at least, that have been referred to this afternoon. And if we ever do anything to reforest the mountains or regain the rainfall we have had, now is the time to commence. Let us begin as hard as we can to push the project along.

MR. T. P. LUKENS

Mr. Lukens, being called for, addressed the Congress as follows:

Mr. T. P. Lukens,being officially connected with the Bureau of Forestry, and for many years entirely alone in the proposition of reforesting our mountains, you may be assured that my heart is full when I see so many men falling into line who have begun to realize the importance and necessity of reforesting our mountains and protecting them against fires. It is very gratifying, indeed. Our chief, Mr. Pinchot, in whom we have the fullest confidence, knows well the necessity and needs of this locality as well as every other locality where there are forests of which he has jurisdiction. Mr. Pinchot has given me the most hearty support that it was possible for him to give with the divided efforts that were being bestowed upon it—for until very recently, until February 1st, the work which should have been and which is now all under his charge, was divided between his department and the Interior Department. Now, it is different. Mr. Pinchot has accepted the entire field, as it was turned over to him, and will as rapidly as possible revise it; and you may rest assured it will be done well. Mr. Pinchot is a man who will be exceedingly glad to hear from the Los Angeles Chamber of Comerce, all bodies and all responsible people who are interested in this work. He will be keenly interested to receive any of your recommendations, and will give them a most hearty consideration. I will say before I sit down that while this project of mine of reforesting the mountains, for which I have been laboring and selling off my corner lots one after another and putting the proceeds into it until they are pretty nearly gone, for so long a time received so little support, and even now has very little support financially from the people, the government now is realizing the value of the work and is going to reforest our mountains. At my left sits a gentleman who has just arrived here from Washington with two assistants, who are sent out hurriedly to establish a treeplanting station in the Santa Barbara reserve, which is one of the most gratifying incidents that has taken place since I began this work. They have that much confidence in the success of this work that they are going to establish other stations immediately, and as fast as Mr. Pinchot can get money he will put it into this work. But the localities must assist in this work. It would be impossible for the United States government to put sufficient money into the project to do the work as rapidly as it should be done. I have 300,000 little trees growing. 50,000 we would like to plant out this winter, but we can't do it, for although Los Angeles people have raised us $1500 it is not enough. It takes money to scramble over the rocks and tear our clothes to pieces. But every tree that it costs us 5 cents to put out, I confidently believe will be worth $500 in the time to come. (Applause.)

EVENING SESSION.

Prof. Cook in chair.

Order called at 8 o'clock.

The Chairman—We have all known for years of the great work being accomplished by Hon. T. P. Lukens, of Pasadena, who has persisted in his work of reforesting our water sheds in the face of little encouragement on the part of the general public.

It is with great pleasure that I introduce Mr. Lukens who will address you on, "Why Reforest the Mountains?"

The Chairman—May I ask you what percentage of trees you plant to the acre? How many of them die after you plant them?

Mr. Lukens—Well, in dry years we have planted very few trees. It was necessary to grow the trees to at least two years old, transplanting once or twice in the meantime; and from them we expect to get a good percentage of them to grow.

Mr. Allen—In replanting, is the aim to plant the trees that naturally grow there before, or are you experimenting with new trees?

Mr. Lukens--We are keeping just as close to nature as possible. We are not planting largely of anything unless we find it has grown in that locality or localities similarly situated, or in the same conditions of soil and climate. We aim to keep them within their zones entirely, and in the soils in which they are found growing. We have only two per cent. of exotics or trees from other parts of the United States.

A Delegate—How do you prepare the forest land? Do you plow it and cultivate it, or how?

Mr. Lukens—It would be a strange looking animal that would pull a plow where our work is being done. In many places there is sixty or seventy or eighty per cent. of slope. We dig with a bar, or a mattock. Where we cannot use a bar we use a mattock. We fix it up the best we can and plant the tree in there.

A Delegate—This timber that grows along the coast here, how does that do?

Mr. Lukens—Such trees we only put in such places in the mountains along the streams. On the slopes of the mountains we only use the trees that we found were growing in similar localities.

Another Delegate--What per cent. of the trees planted survive?

Mr. Lukens—We have not been planting many trees in the past. The trees that we have planted are two years old, and they have been once or twice transplanted. A good per cent. of them grow, and we hope to carry out the work. Of course, if there comes a very severe drouth after the planting, we will not get as large a per cent. of them to survive. I will say, however, that we do not anticipate any trouble.

A Delegate—What did you first plant?

Mr. Lukens—We first planted seeds, and we had favorable conditions. We have a few trees now that are ten feet high.

The Chairman—I understand that Mr. George W. Peavy, of the Bureau of Forestry, Washington, D. C., who is on his way to Santa Barbara, is with us, and we shall be glad to hear from him.

Mr. Peavy—Mr. Chairman, it is a pleasure, I am sure, to be introduced to this body of business men. I am not here, as Mr. Lukens has said, to talk very much, but to go up to Santa Barbara and put some seed in the ground and see that it grows.

As to the necessity of reforesting these mountains, I think that question has been pretty well covered. We have plenty of mountains in Southern California here which need reforesting, and those mountains will never be made to retain this copious rainfall which you are having now unless you get trees up there which will retain that moisture and make a sponge, as it were, upon the ground to hold that moisture upon the ground.

Now, I may say of the proposition which is before me, that I am sent out here by the Bureau of Forestry, to reforest some of this country. I am going to Santa Barbara and will do what I can to conserve the water which is to supply that city. I might speak of the necessity of that, but all that has been covered in your sessions today. There is nothing that needs to be said.

As to the future policy of the Bureau of Forestry in the work in this locality, of course, I am not authorized to speak. However, it seems to me, as Mr. Pinchot, the Head Forester, has said, that with seventy millions of acres of forests or forest lands under the control of the Bureau, that the great proposition in the future is reforesting these mountains; and these forest lands are to be reforested, not for the sake of reforesting alone, for water conservation alone, but are to be reforested for us, for the use of the American people. These seventy millions of acres, and more which will be added from time to time, are to be a vast heritage to be handed down from generation to generation. That is the business which is before the Bureau of Forestry or forest service.

This is absolutely and entirely unexpected. I did not know that I would be called on to face this audience. I thank you for the honor.

Mr. Post then read two papers, "Value of Sewage for Irrigation," and "Impounding of Flood Waters," prepared by J. D. Schuyler and Samuel Storrow, of Los Angeles.

Mr. Post: Mr. Schuyler and Mr. Storrow both regret that they are unable to be present at the Congress. In addition to the subject given on the program. I have been asked to present the paper on the "Value of Sewage for Irrigation," originally prepared to be presented here, as the manuscript on the "Impounding of Flood Waters" has failed to reach us on account of the storm.

VALUE OF SEWAGE FOR IRRIGATION.

In the need for additional water supply, the questions divide naturally enough on what can we do at once, without legal complications, cheaply, and those which require extensive investigation and united effort. In the first class the utilization of sewage stands out clearly.

It belongs to the category of smaller beneficial actions which are now feasible and which need not be delayed by the peculiar water litigation habit of Southern California.

What is known as the septic process of purification of sewage consists of treatment by known bacteriological methods.

The usual putrefactive processes of Nature combine the organic substances present with a certain amount of oxygen. The nitrogenous matters are reconstructed with the giving off of ammonia or possibly of free nitrogen, oxides of nitrogen are formed, nitrous and nitric acids, carbonic acid, sulphuretted hydrogen, marsh gas, etc. This putrefactive process is materially assisted, if not wholly brought about, by the life action of certain small organisms called bacteria or microbes. These small organisms, by the process of their economy, utterly destroy all the organic compounds with which they come in contact, even to the extent of making a full meal of those of their late friends who may succumb to the infinitesimal struggle for the survival of the fittest. A full recognition of the essential part in all putrefaction played by these bacteria is essential.

The purification of sewage is the oxidation of the organic contents, chemically shown by the nitrogen appearing wholly as nitrates, biologically shown by the growth and change of the bacterial life through a cycle ending in the complete extinction of such life. Since the bacterial life is the cause of the chemical change and is itself dependent upon certain chemical and physical conditions, we have in our hands a simple control of the whole putrifactive process.

The sewage enters first an air tight and dark chamber or tank, for the action of anaerobic bacteria, for some hours. The result of this is a complete digestion of all semi-solid constituents, and the resulting effluent of the tank is a nearly colorless liquid.

The next step in the process is to provide light and air for this effluent, for the action of aerobic bacteria, and this is best accomplished by simple furrow irrigation.

Here is where the municipality should meet the irrigator, and should see to it that the valuable asset held by it shall be made to serve a mutual economic advantage.

In the arid or semi-arid sections of the country the water contained in the sewage, aside from any manurial value of the organic contents, has a very great value for irrigation purposes, a value that may often be saved by some simple treatment.

The sewage flow of Los Angeles equals about 800 to 1000 miners' inches. It has been decreed here that sewage shall not be used for the irrigation of certain crops, because it is feared that onions, strawberries, tomatoes, radishes and celery may transfer raw sewage from the fields to our mouths. There is some such danger if the irrigation is improperly or carelessly done and the sewage has not first been properly and sufficiently purified. If the crude sewage were first subjected to the hydrolytic action of the anaerobic bacteria in a septic tank and then to the nitrifying action of the aerobic forms in properly constructed bacteria beds, the effluent could be most safely used for the irrigation of any and all crops of vegetables, and the manurial values being still retained in the purified effluent, the value of the sewage for irrigation would be materially greater than the value of clear water. It would be very interesting to compare the slight cost of so altering the present sewerage system of Los Angeles so as to incorporate a septic tank, a part of which can be the sewers themselves, and a deep coke bacteria bed, with the original cost of the present outfall sewer and the large outlay which is now being put upon it immediately to rescue it from destruction; and also to contrast the annual cost of maintaining a system that sold 800 to 1000 miners' inches of purified sewage with the present system of paying a big price to throw away the greater portion of the most valuable property the city possesses—the irrigation water supply which flows in her sewers.

Properly purified by these inexpensive methods described, the sewage of Los Angeles should yield a handsome revenue—greater than the revenue derived from the sale of river water in the days when it was mostly used for irrigation directly from the stream.

It is proposed that the purified effluent be limited to use on such crops as walnuts, to which no objection, be it practical or sentimental, can obtain. Sanitary engineers find that the sewage waters thus treated are purer than many surface wells.

Much explicit information on this point could be presented, but it is perhaps sufficient to say that the State of Massachusetts, which is in the fore front of sanitary legislation, allows such treated sewage to be turned into natural drainage lines and streams as non-contaminating waters,—a position which has been sustained by numerous court decisions in Massachusetts as well as in New York and England.

IMPOUNDING OF FLOOD WATERS.

From an academic standpoint, the desirability of Storage Reservoirs is undisputed. We do not reach the theoretical limits of our water supplies until the last drop of water has been prevented from going to the sea, has been impounded or beneficially used upon the ground.

Yet at the outset we are confronted with the fact, that of the storage sites in Southern California, which are feasible, many are not utilized. Recognizing this fact, we naturally inquire why have they not been utilized.

The intelligence to utilize natural advantages is here, the wealth to develop them and the market to use them. There must be practical difficulties. Any one familiar with water conditions has not far to go to stumble on some of them. The difficulties may be legal, or financial or physical.

The legal difficulty includes obtaining a clear title to water and then maintaining possession. The storage of flood waters, to be used on lands riparian to the stream would seem to be simply a case of appropriation of unappropriated waters. Yet throughout Southern California the low water or normal flow is already appropriated, and litigation may be expected in the absence of legislation, over the questions of what is legally storable, what is flood discharge, and what is usual flow, and whether flood waters feed the great gravel reservoirs of our artesian wells and pumping plants, and whether these will be injured in a legal sense by intercepting flood waters.

As to financial difficulty the reservoir proposition must pay. In a large sense from a public standpoint, almost any reasonable reservoir would pay. But, with legal and economic conditions as they are now, as an investment proposition, even public spirited men, bent on development of their community may well feel discouraged, when obliged to compete in the money market, with Los Angeles real estate, oil, mines and the numberless investment opportunities of Southern California.

A reservoir costs money. A corporation or an individual furnishes this money and therefore has an interest in it. The reservoir supplying water not before obtainable, produces an appreciation in the values of lands which before could not be irrigated. Therefore the land owner is interested. The irrigator who is to use the water has an investment in crops and a field of labor. He is interested. The holder of vested water rights is concerned as to the effect of the new work upon him. He is interested. The public, desiring economic development of the community, is interested.

The solution would seem to lie in an equitable adjustment of responsibility and benefit among all these interests, so that each may take an active part in forwarding the enterprise.

It is of prime importance that this Congress should begin such a solution, determine and initiate a policy which will induce an era of reservoir building in Southern California.

We are not without examples of such solutions.

For instance, in Arizona, the water users association of the Phoenix Valley have settled all their family quarrels, and will receive the benefit of the Great Tonto Reservoir.

Similarly the interests concerned with any one of the possible reservoir sites should unite, harmonize their individual differences, and make it possible for capital whether it is advanced by the Government as in Arizona, or by local corporations to enter the field and carry the work to completion.

So much for financial and legal obstacles. Clear away these and the body of engineers of Southern California may be trusted to clear away the physical obstacles, to determine the facts of flood supply, of costs, of permanency; in short of engineering feasibility, which, combined with legal and financial feasibility, will sanction a given work.

Many situations which at first glance seem possible sites, upon investigation must be eliminated from the list of practicable constructions, because of various conditions.

Some are so situated as to require a flood supply conveyed from other drainage areas, a condition desirable enough on theoretical grounds as minimizing the silt problem.

Some are simply sites without sufficient supply, whether due to insufficient rainfall or feasible drainage areas. Others, situated across torrential streams, can measure their life in decades before being silted up. True, their height may be constantly increased, and the reservoir will gradually assume the character of Mr. Mendenhall's gravel storage basins (or those described by Mr. Trask), but their costs are correspondingly increased.

Perhaps the number of possible reservoir sites will be reduced to a dozen feasible ones, on thorough study and examination and the determination of facts.

Attention will now be drawn to some storage possibilities. A pleasing, and it is to be hoped, a not utterly useless occupation.

Mr. Lippincott has already spoken of a number of these here listed. The data for areas and capacities here given are taken from published maps of the U. S. Geological Survey.

Turning to the Santa Ana River, a reservoir site exists on the main fork above the junction with Bear Creek at Alfilaria Flats, which would supplement the famous Bear Valley dam. With a dam 100 feet high, it would have a capacity of 10,000 acre-feet. This is interesting not only because of the value as an irrigation matter, but electric plants below this site are installed and the storage water flowing through their machines would benefit them to the extent of 1500 H. P., for which they could afford to pay $15,000 annually. The capital corresponding to this sum at 5 per cent. is $300,000, which, if it could be arranged, would go far toward building the dam.

Lower down on the Santa Ana River opposite Riverside, the Salt Lake Railway recently built a concrete bridge, probably determining the depth to bedrock at the dam site at that point. A dam at this point 50 feet in height would back water up one and one half miles, cover 2 1-3 square miles and have a capacity of 20,000 acre feet. A dam 100 feet high would quadruple this capacity. The mountainous drainage area, tributary to it, is about 400 square miles.

The Santa Ana river has a large drainage, a large runoff, and is now stored only in a minor tributary by the Bear Valley dam and by thirsty gravels. These sites are good examples of the need of joint action, without it they will remain unused.

Between Redlands and Los Angeles at various points along the foothills are small buttes or hills; enclosing in a crescent shaped form two or three sides of possible reservoir sites. These are often at considerable distances from sources of flood water supply, and require joint action. As they stand they are bank safes without money in them, while across the innocent looking divide there may be plenty of money but no bank safe. They have a distinct superiority over reservoirs across stream channels, in that their silting up can be avoided.

The maps show a site of this character along the line of foothills south of the line of the Southern Pacific R. R., between Los Angeles and Pasadena. Midway the foothills are pierced by a small drainage line. Apparently a reservoir site exists here into which the floods of the San Gabriel and Arroyo Seco might be thrown.

Coast. Along the coast northwest from Santa Monica are a half dozen small streams now wasting into the ocean, each with its natural geological basin for a reservoir site. These tiny streams might supplement the Malibu and Triumpho Reservoirs of which Mr. Lippincott has told you, feeding into the same system which would conduct these waters to the lands between Santa Monica and Hollywood. Individually they are of no importance. They suggest, however, that the works may gradually be extended over a series of years, paying something in immediate return as it proceeded. On the Upper Triumfo, in Ventura County, a concrete dam reservoir is now under construction, which Mr. Koebig can tell us about, and perhaps with the exception of works at San Diego was the only dam built last year in Southern California.

The Ventura river also wastes into the Ocean at the town of Ventura a probable minimum of 250 miners' inches. Ideal storage could be obtained on the mesas around Nordhoff.

The Santa Clara River in Ventura County is a great spendthrift, wasting into the ocean, and the dam sites on the Piru Creek, spoken of by Mr. Lippincott, are of great value.

San Diego County has important reservoir sites, as at Warner's ranch, and it is to be hoped that a united effort be made to secure rainfall and flood observations which will determine their economic limits and feasibility.

In conclusion the Congress is urged to impress upon communities, associations and governing bodies, the importance of obtaining long in advance, the preliminary data of rainfall, stream flow, and flood discharge. In this work the U. S. Geological Survey has long aided Southern California, collecting exceedingly valuable data, which, however, for the purposes discussed in this paper, should be greatly extended.

Finally, it is to be hoped that the Congress will successfully initiate a policy of reservoir building in Southern California.

This paper, which Mr. Storrow prepared for the Congress, was received too late to be read, but is now inserted in the published proceedings.

THE STAGE OF FLOOD WATERS.

In the few minutes allowed for the reading of this paper, few facts or statistics can be given. I must ask you to search your memories for the observations of facts to prove or disprove my statements.

You have all seen the sudden rushes of water tearing down our main streets after a hard shower. Spring Street on a rainy day is familiar to us all, a dirty flood from curb to curb, knee deep, and swift; a large volume of water if we could save it to irrigate a few acres. Possibly you have wondered where that water went, and if it could be put to some profitable use.

As a large example we have the Los Angeles river, usually a nearly or quite dry gravel bank, a free supply of dry sand and gravel; sometimes a raging and rushing torrent the more devastating because its very condition of depleted dryness lulls us to a false sense of security. One of the branches of the Los Angeles River is called in Spanish "The Dry Ravine," Arroyo Seco. So dry is this dry ravine that only three times have I seen it discharging water into the Los Angeles River. Another branch is the Tejunga. Twice have I seen the floods of the Tejunga pass the Southern Pacific tracks in the San Fernando Valley and once reach the Los Angeles River. I have been told that twice since I have lived here (off and on since 1890) the Los Angeles River has discharged, as a surface stream, into the Ocean.

Whence came these floods and where does the storm water of our streets go; and the flood waters of Arroyo Seco, of the Tejungas, of the Los Angeles River, of the San Gabriel, the Santa Ana, of the canyons sometimes discharging into those streams and the many more that do not?

The rain falls on the just and on the unjust, on the mountains and on the plain more, much more, on the mountains and sometimes but little on the plains. The vertical depth of he year's rainfall in Los Angeles varies from five inches in the rainy season of most deficient precipitation to eight times that or forty inches in the year of the flood; the average is less than half the flood, and possibly three times the minimum. The rainfall in the higher mountains is possibly about twice the rainfall of Los Angeles. The total area from which the rains and melted snows drain towards the Los Angeles River is so great that this total rainfall is annually enough to cover one million acres with water a foot deep or to properly irrigate one-half million of acres. Add to this the vast totals of the San Gabriel River, the Santa Ana River, and the many small canyons. Compare with this great total the few paltry thousands of acres we actually irrigate. Think of the loss. And yet I have said that only very seldom do these streams discharge surface flow into the Ocean.

* * * * * * * * *

The rainfall is our water supply. The mountains catch more rainfall on square mile of their precipitous sides than falls on two square miles of the plain. The mountains discharge great floods, in sudden rushes through their rocky canyons, out onto the gravel covered plains. The rainfall on the plains either sinks at once into the ground or starts in comparative quietness on its journey down the gentle slopes and soon is lost by seepage into the ground. In any event, that part of the rainfall not otherwise disposed of sinks into the ground.

Of the water that falls as rain or snow, some is at once evaporated back into the air. Some (much more) is evaporated after it has gotten further along on its journey but before it reaches the roots we wish to irrigate. Some, probably far the greater part, drops downward through the soil and joins the great body of underground waters which we tap by underground tunnels, or galleries or by walls, for the supplying of this city or the thousand and one other worthy or unworthy consumers of water. Of the water which, in the mountains, sinks into the ground, quite a considerable amount comes to the surface again at a lower level as a spring feeding some surface stream. If all conditions are favorable these springs may flow throughout the year. Human artifice can partially regulate the flow of these springs as by tunneling into the water-bearing gravels, or by other means, and so somewhat readjust the rate of flow throughout the days of the year and even year by year. But human effort, Mr. Hatfield to the contrary notwithstanding, does not materially affect the total supply, but merely its availability.

The gravel deposits into which the rainfall directly sinks or to which it is brought after a longer or shorter journey over the surface, are our great natural reservoirs or conserving places, rendering the winter's rains an available and acceptable water supply during the rainless summer months. These gravel deposits and their yields of water are known to you all.

The City of Los Angeles gets virtually all its water from the natural, or artificially stimulated, drainage from the great gravel banks of the San Fernando Valley. The City of Pasadena drains a large part of its water supply from the gravelly bed of the Arroyo Seco. So, too, with almost every city and town of Southern California and many, very many, elsewhere. The underground waters, drained by gravity or by pumping from the gravelly beds of streams, are considered of superior and uncontaminated purity for domestic purposes and are all too often the only waters available for any purpose.

* * * * * * * * *

We often think of the storage of water supplies as including the building of great reservoirs, surrounded by great embankments or controlled by massive dams of earth or masonry. The word reservoir usually calls to mind some such picture, with a long vista of rippling water; built on a hill top and fed by a wonderful pumping plant throbbing great heart-beats of life-giving water from some nearby stream; or a massive pile of earth or masonry built across a mountain valley, a monument to some engineer's skill and daring in damming the natural, or artificially assisted, flow of the stream. We are told how many millions or billions of gallons of water the great reservoir safely holds, or sometimes the sadder story of somebody's mistake, a broken dam and a Johnstown Flood.

* * * * * * * * *

The essence of these reservoirs is that the water shall be stored to be used at the time of demand, and, if possible, shall be used by gravity flow. We therefore aim to build our great reservoirs pretty well up hill which is also near the source of supply, but often not near the point of use, at which latter place we often build smaller reservoirs, and frankly call them "distributing reservoirs," while the great reservoirs in the mountains are looked upon as sources of supply. The proper selection of an acceptable site for these mountain, or supply reservoirs, with an appropriate site for an impounding dam, is a matter of a high order of engineering skill, assisted by a kindly predisposition on the part of the All-wise Providence. Here in California Providence has been both lavish and niggardly. The valleys at Sweetwater Dam and at Hermet Lake seem designed almost on purpose for the wonderful dams built in those places by Mr. Schuyler; while the steep and narrow mountain valleys on the head waters of the Los Angeles River and the San Gabriel do not seem to offer such advantageous sites for large reservoirs. Numerous sites offer in the foothills and on the plains for small reservoirs and we have the reservoir-like action of the gravel-filled valleys as a means of storing the otherwise lost winter floods for use during the time of our summer need.

The actual building of earth embankments and low earthen or masonry dams on well-chosen sites in the foothills is a matter more of attention to the details of a mechanical trade than a display of engineering skill. The choosing of the site is the more difficult job, the more especially as it is not absolutely proven that any simple and convenient sites exist, and it is even less evident in the absence of a systematic search that such sites do not exist.

Mr. A. H. Koebig was called upon by the Chairman and addressed the Congress as follows:

Mr. Koebig.—It was only proposed to discuss the questions suggested by the papers, and I may say I am entirely unprepared. Conservation of water, water supply, rainfall, and usage of the water has gone so far in the flesh and blood of every engineer who has made his residence in Southern California, as I have done for the last twenty years, that even when we are unexpectedly called upon we have some little to say. The papers which have been read here during the day have so ably discussed the phases of the water supply and conservation of the same, as well as the usage of the water, economy of use, etc., that there remains very little for me to say.

I think we can, however, classify these papers into two groups: First, the papers which dealt with the conservation of the water; and, second, those which dealt with the economical use. The conservation of water is done by first the reservoirs; second, underground reservoirs; and, third, return from the irrigation waters.

The drawing on our natural water supply in the underground reservoirs, in my opinion, is a very dangerous proceeding, because we have already more than exceeded our supply by far. It is impossible to believe that we can go on and pump water out of our great storage reservoir basins, in the San Bernardino, Pomona, San Fernando valleys, and others, without limit. To my knowledge in the upper levels of these valleys, the plane of saturation has already within the last ten years been lowered about 150 to 200 feet. We have pumped the water which has been stored for years, and hundreds of years, in those reservoirs, and used the same to conserve our business and our prosperity; but we soon will come to the point where we will have to call a halt. Even this copious rainfall which this season has so kindly come to our rescue will not be able to furnish a small portion of the demand which pumps now require. Water saturates the ground, and then it runs off. Storms saturate the surface, which takes up a small portion of the water, and then the water runs off. If we should endeavor to conserve our homes and our business, we must do it by storage reservoirs in the mountins and by foresting the mountains.

The storage reservoirs will enable us to bring the water from the higher levels to the arable lands, use it there, and from there a large portion, at least fifty per cent., of the water which is used for irrigation will find its way into the underground reservoirs. There the water can be used over and over again. This, in my opinion is the only way to conserve and protect our agricultural prosperity and the prosperity of Southern California. It is a subject on which I could say many more things, but I do not wish to intrude on your kindness, and therefore, I will thank you for the attention you have given me. (Applause.)

Mr. Frank H. Olmsted was called upon by the chair and spoke as follows:

Mr. Olmsted.—As we go from here tonight, I suppose we will all ask ourselves the question, "Out of this Water Congress, do I go home more encouraged for Southern California, for the future of this country that I love, than I was when I went to the Congress?" Well, I think I can tell you that we can go home encouraged—everyone of us. Perhaps I am naturally an optimist, but I believe in Southern California, and I believe in our water supply, and I believe perfectly that from this water supply which we have now proved insufficient, there is engineering ability, there is foresight, there is capital, there are enterprising men here who will see that we get the water. There are a number of ways we can get it, but first of all, it strikes me that in every way in which we can add to the information of the subject, we are helping the cause. Without a definite plan we can gather data with reference to our water supply, and that is incumbent upon each one of us. If we are living upon a ranch and can only systematically observe from month to month the fluctuation of the water plane in one well, that may mean a good deal to those of us who are engineers working in this field. Every year there is an accumulation of data on this subject which will ultimately help us to solve the problem.

I am very desirous of seeing either in California as a state or in these southern counties a commission which will, year after year, along defined and well-planned lines, provide for our future needs when the incoming population has increased to such a point that our visible supply of water for today is entirely inadequate. And that time will come. I think it is evident to any reflecting person that Southern California is destined to a future which, on the face of it, does not yet appear. The real causes which will make Los Angeles a great commercial city are not yet in operation. The Panama canal, the direct eastern outlet, the completion of the San Pedro harbor, the Pacific Coast development, the Pacific Ocean development commercially for the next hundred years—all will plant between San Bernardino and Ocean Park a population such as now we can with difficulty conceive; and when such a time comes, there will be need, and before that, also, of very extensive water development. In the meantime, we need to be gathering the data and to be securing the routes which will make this development possible.

Some two or three years ago, when I was in the mountains for Mr. Kerchoff, looking for power, I saw a lake three hundred and twenty-five miles away from here, which was not available for a power proposition. But I spoke to Mr. Mulholland about it, and said. "Los Angeles ought to own that lake. The watershed above it has an average elevation of over 1100 feet." When I was there in August there were great snow drifts there 40 feet deep. That water at that time could have been located by the city of Los Angeles, with an expenditure of not over one hundred or two hundred thousand dollars. That water could have been thrown through a tunnel into the river and if it had been a hundred years before we needed to say, "This water is ours, Los Angeles needs that," we could then have gone there and taken it. But we cannot do it now; it is too late. But there are other possible chances of that kind, and I say, that Los Angeles and Southern California, ought to organize a commission that will seek out these various possibilities, and at last when the time comes for action we may be equipped with all the knowledge that will enable us, with all the money that will then be available for it, to do these things. And so, as we go from here tonight I wish all to take heart, because it is not a pessimistic outlook. There is lots of hope, lots of water, and lots of future. (Applause.)

Mr. Cuttle, of the Riverside Water Company, was called upon by the chairman, and spoke as follows:

Mr. Cuttle.—I am not an engineer by profession. I am a practical water man and have had some years experience in developing water and in irrigation at Riverside. We all know what many of you gentlemen have told us, that the underground waters are decreasing, possibly faster than they are coming in. The question of conserving these waters is a very grave matter. I have no solution for it. I have no theory at present, except what has come to me second-handed. One of these ideas is the distributing of the storm waters at the mouth of the canyon in the sand and silt, and allowing it to soak into the sands, thereby filling up the canyon is a surer way than if they were let alone. We are doing a little work of this kind now in connection with our company. The water in the Santa Ana river today is very great, and with a little money spent in this way no doubt the returns will be very great. We will take this work up and push it as far as we feel able to this year; and we are going to attempt to form a permanent organization for this purpose, to take care of the flood waters.

I am entirely unprepared. I had no idea that I would be asked to say anything. I thank you for the kind attention you have given me. (Applause.)

A Delegate.—How do you do that kind of work?

Mr. Cuttle.—The work for the present is building dams of the boulders, just as they lie on the ground. We place them sufficiently high to divert the water from the main channel, into dry washes. In all these streams, or in the beds of these streams, will be found dry washes. There are many of them which have no water in them, while in the main channel the whole stream will be found. By diverting pretty well toward the mouth of the canyon, the water is diverted into these dry washes, and it will sink into the sand. Mr. Trask had an able paper on that matter today. I do not quite agree with all his theories. As I understand him, he says that ditches should be run at right angles to the main stream and water diverted in those ditches about 500 feet apart down stream and at right angles to the stream. It would be almost impracticable to do that, on account of the condition of the country. His idea, as I take it, was to flow the water from one ditch to another, allowing it to soak into the ground, The ground is so uneven and the bed of the streams so uneven that it would be almost impossible to do that; and the only means we have followed so far is to divert them into these washes.

Some people have taken up lands, I understand, in certain sections of the country for the purpose of securing boulders for building purposes. I have heard that some people have taken up those lands with the idea of keeping other people from getting the boulders. This work has to be carried on carefully, for the reason that by turning the water into these dry washes, they may get onto some of this land which is valuable and cause many damage suits. I think there is some work that can be done along the line of securing lands for the purpose of distributing water. I have been told that there is a lot of land available in this way. Perhaps in another year dams may be built at a level sufficient to deliver the water without taking the whole flow of the water. Perhaps a certain amount can be diverted into these other portions when the flood comes. The idea is to build the dams so that the bulk of the water will go over the dam and not cause damages to any lands.

A Delegate.—I would like to ask Mr. Cuttle if any attempt has been made in the diversion of these storm waters to conduct the waters through the medium of shafts or holes in the ground, below the strata, holding them below the surface. I presume the water will gather in the porous strata but might not reach the lower strata which might be valuable for storing the water. Has any attempt been made to do that?

Mr. Cuttle.—No attempt has been made to force the water to a lower strata. If the work could be followed up and carried out carefully, it could be made to lose itself in these dry washes.

Mr. Parker, of Orange County, was called upon and addressed the Congress as follows:

Mr. Parker.—I have been an irrigator in Orange County for a good many years. Toward the mouth of the Santa Ana river the valley spreads out like a fan, and a great amount of the waters that come down the river in the winter time goes into that great valley below. Above Anaheim they have been putting in a great many pumping plants in the last three or four years, and the water is pumped and used upon the lands all the way down as far as Westminster. It has a tendency to go back into the ground and settle down to the lower strata and then it can be used over again as it goes down through the valley. I have noticed the same thing in the San Fernando valley. It makes a great storage reservoir and all of this storage reservoir is a benefit to the people.

There was one subject that came up today in reference to the cultivation of orange trees. I don't quite agree with our friend that believes in plowing up the surface roots as much as he does. I believe in studying nature as much as possible. We all know that it takes the sun, the land and the water to produce vegetation, and of course the better the conditions, the better the results. Therefore, I don't quite agree with them in the idea of cutting off the roots after the tree gets established. In the first cultivation of trees their theory I think, is correct, keeping the moisture down as low as possible, and the roots as low as possible; but out in the forest we notice great trees which grow to immense height, and we notice also that the roots come close to the surface. Where you see a tree blown over these surface roots are not very deep in the ground, and I think that we get fuller fruit and better fruit where we get surface irrigation. Of course, the theory is all right, but I don't think it is a good idea to cut the roots of the trees off for the sake of getting the water down. In my observation of the cultivation of orange trees, I would cultivate from the top during the summer, but in the spring I would plow my ground at least twice and I would cultivate not more than three inches deep on top. In the winter, I would break it up five and six inches. Wherever you scratch and cultivate, you form a crust. The object is to break that crust, and with the plow in the spring to leave the ground naturally as it was before you irrigated; that is the silt and stuff has a tendency to form a crust which needs to be broken up. I don't think it good policy to go much below six inches in plowing. That has been my observation.

Mr. Cuttle.—The matter of the artesian wells was brought up today, and I might say that a bill has been prepared by Mr. Haskell, of San Bernardino, known to most of you, and endorsed by the Riverside Water Company, and by all the water companies of Riverside, making it a misdemeanor to permit artesian waters to go to waste. The bill describes what waste shall be, and it is everything but domestic use or irrigation of lands for the purpose of raising crops. I understand it has passed both Houses of the Legislature and it will probably become a law.

Mr. Olmsted.—Mr. Cuttle, I do not believe we could stand for that in Los Angeles where we are wasting about a thousand to twelve hundred inches of sewage water into the ocean every day. I do not think that would be consistent.

Mr. ....Parker, of Los Angeles, was called upon by the Chair and addressed the Congress as follows:

Mr. Parker.—I feel my inability to make any speech at all to these gentlemen. I have only been here in Los Angeles a matter of six years, and I am not as thoroughly conversant with the requirements and necessities of California as the gentlemen who spoke this afternoon. I have been in touch with the engineering work since I came, very closely, and I have had some experience in the line of water development. All engineers necessarily appreciate when we come in contact with California and the water development, the requirements and importance of water to this country. I was especially impressed with Mr. Mulholland's talk this morning, and with the papers which were read tonight. The question of the irrigation water which is going to waste from artesian wells is a very, very serious question. In connection with some work which I had at Long Beach the last two years, I have seen the artesian basins down there. I have seen a matter of three to four hundred inches of water going to waste from as many as four to six wells, wide open all the time. Now, that certainly should be stopped. I hope Mr. Cuttle is right in saying that the Legslature will pass the bill.

There are so many papers which have been given today that I will have to confess my inability to discuss them. I thank you for your courteous treatment of me tonight.

A Delegate.—Can you tell how to cap an artesian well, Mr. Parker? That is, presuming you cannot top cap it.

Mr. Parker.—Why won't the top cap do it?

The Delegate.—It may come up on the side.

Mr. Parker.—As a rule that will do it. I have seen that done in a number of cases, probably as many as 20. It perhaps cannot be done in some instances, but I have seen fully 20 of the large ones in Southern Californa capped in that way. I believe it can be done in the majority of cases—certainly where it can be done it should be done.

Mr. Cuttle.—I would like to answer that question by giving my own experience. In many cases the water will come up outside of the casing where the well is capped. One method is to put a plug of concrete around the casing, carrying it out far enough to check the flow of water and allow it to set while the well is flowing and afterwards cap the well.

That is not always successful. A better method and one which is successful in nine out of ten cases, is to take cheap piling and drive outside of the area where the water comes. That can easily be done. We are preparing now to use a light pile driver for that purpose, and have a special light piling made with a loose tongue and groove, and drive this piling in a circle in a distance of 15 to 18 feet, and perhaps 20. Then we place in the concrete, allowing the concrete to set while the water flows. When it is set thoroughly we cap the well. If that is not clear to any of you gentlemen, I will be glad to give you the matter in clearer form.

SUMMING UP

Ladies and gentlemen, I regret to see on this program this summing up which was put here without any expectation or desire on my own part; but I will say a few words.

I remember in another state, a long ways from here, some years ago there were some very fine peach orchards; and a terrible enemy came into them, peach yellow. When it first came, everybody said, "Say nothing about it," and in a certain sense there was a policy there, because many of them would sell better; and I regret to say many of them were sold. It was a terrible enemy, and as nobody was studying the nature of the case, the orchards all went to pieces. One of the best peach orchards in the world came to naught. A little ways from that orchard there was another orchard, no better but equally as fine, and the owners started in on another basis. They studied the disease and found out all they could about it, for the purpose of coping with it. Today that is a famous peach orchard.

Now, it seems to me that is a pretty wise thing to do. When there is a menace, let us stare it in the face. And ladies and gentlemen, we have a menace, and my friend Mr. Mitchell called attention to that fact today, that wells which 11 years ago were flowing, are being pumped today at a depth of 95 feet. It certainly is a grave matter, and it seems to me it is time to give it careful consideration. I am a good deal happier about it. I have great faith in California. I believe in it thoroughly, and I believe it is none too soon for us to study this matter in all its phases. I believe we will all go home with a great deal more faith in the matter, and I would suggest that we try to impress upon our friends the truths which have been presented today.

Now, my frends, we have a magnificent country. I don't think its superior exists in the world. We have a magnificent prosperity agriculturally. Perhaps I had better not say much about that. They mention it to us when we get to talking about railroad rates. But, when magnificent orchards in the crops of three or four years have been paid for at a great big price, that is a wonderful showing. We have a magnificent prosperity agriculturally. The reason for this, and the reason that people from abroad are attracted to this country is largely our citrus orchards. We are proud of them and we may well be. We do not want to rejoice over the ill-success of others, but when that ill-success affects us, we may well consider it. There is nothing wrong in doing that. Florida has got a very black eye this year. And Italy right on top of it, although they do not produce such excellent citrus fruit as we do. The lemons of Southern Italy are not equal to our California lemons, and no orange in the world equals the Washington Navel. That being so, Mr. Mendenhall's caution comes none too soon. Last year in our section 50 acres were put out, and this year over a hundred. We had all we could take care of before. There is something so beautiful about this and about the prospects in view, that it is no wonder. So I say again, these questions are coming none too soon. It seems to me we ought to do all we can to inform the people along these lines.

It was not my good fortune to be here early enough to hear much of Mr. Lippincott's paper, so I don't know much about what he said. I was pleased to hear about the reservoirs, and I hope this magnificent committee that we have now will make full use of the information and set in line actions and energies that will develop something that will be of use to us.

Now, we do not know that the rainfall will be any greater, and if we can avail ourselves of these waters and save them from running off, it is our duty to do so. The subject is certainly worthy of consideration. We have got this able committee and we know they are enthusiastic in favor of Southern California and its prosperity, and we know they will carry into effect these propositions that have been given here. And if Mr. Trask is right, and if Mr. Cuttle is right, all the methods he has spoken of, which can be used to save the run-off and bring this level up as it used to be ten or eleven years ago, is a good thing; and it is good that we have had this Conference.

The paper by Mr. Mulholland was remarkably good, and we all appreciated it. There is no question but that the meter business is a good one, and I hope it will be carried out wherever it is needed or necessary. Let me tell you that it is the right thing to save the water in any way that it is possible.

It was said this morning that some people are using only one miners' inch to ten acres and others one miner's inch to three or four acres, and conditions equal, and one orchard as good as the other. Those are eloquent words, and they ought to make us all glad. There is a grand chance for conservation of this soil moisture, of better cultivation and deeper cultivation.

When we come to the pumping, if we can save water there it will be well. We have two committees at Pomona working on that project. I believe we will succeed. We are not so stupid that if we can save in three or four years enough to put up our whole plant, as not to do that thing. We are having conditions studied by competent men. We are going to have a centralized power plant, and we are going to consolidate these interests and we are going to save that. These expenses this year, it seems to me, are terrible expenses.

Then the matter Mr. Mitchell presented so ably this afternoon is a matter we are all tremendously interested in. Let us do all we can to stop this waste of forest by fires. It is enough to give us the nightmare to think that almost any night we may wake up and find the forests in the canyons going up in smoke. If we cannot stop that any other way, we had better stop people going into the mountains, entirely, because as Mr. Mitchell says, they belong to all of us.

Mr. Lukens gave us something in the line that I have just mentioned. Now, I don't know whether we ought to have resolutions or not. Very likely Mr. Boothe may have some to present, but if it will add anything to the strength and energy of this body to pass a set of resolutions, referring these matters to the committee, I think we should do so. It is our duty to help them in every way possible and give them all the encouragement we can. Is there any other matter, resolutions, or anything that will help the committee? We shall be glad to hear from Mr. Boothe on the matter.

Mr. Boothe.—Mr. Chairman, I have not prepared any resolutions, and I don't know that any have been prepared. Perhaps following the suggestion made by the chairman, it may not be amiss that this congress should make a resolution that the committee which has been mentioned now covering all of Southern California should be instructed or requested to take this matter up in a live, energetic way and proceed to study the necessities of Southern California, the resources of its water supply, and the use of water and collateral subjects. I should prefer that would come from somebody other than myself, for the reason that I happen to be on that committee, and at present the chairman of that committee, and I do not like to offer a resolution for you on that subject. If it is the idea of the congress, I have no doubt that the committee would be glad to have a resolution of that kind, and it would be somewhat of a basis upon which they might work.

The Chairman.—Has anyone anything to present in that line?

A Delegate.—I cannot incorporate all Mr. Boothe suggested. The importance of securing a man we fully appreciate, and the great importance of preservation of the watershed, and a thoroughly competent man to supervise the control of the reservations of Southern California. I move that it is the sense of the delegates of the Water Congress of Southern California assembled in the Chamber of Commerce at Los Angeles, March 13, that we recommend that the Southern California section of the National Irrigaton Association canvass the situation and recommend to the authorities at Washington the appointment of a safe and competent person.

The Chairman.—That motion is something like the motion by Mr. Braly made today and afterwards withdrawn.

Mr. Cuttle.—I have a motion to make. I move you that it is the sense of this convention that the Southern California Section of The National Irrigation Association be requested to secure the enactment of such laws as will prevent the grazing of cattle and sheep upon the forest reservations, and also making the forest reservations game preserves. I think the appointment of a man should be left to that commttee or the gentlemen of the committee as the most important part of the business. We want to get at the principle first, and we want the game reserves; we want to keep fire out and we want the other proviso also.

Mr. Boothe.—I second the motion.

A Delegate.—This is very much along the line of Mr. Robinson. Mr. Robinson refers to the pasturing and the passing over it.

The Chairman.—Something like that was passed today.

Mr. Cuttle.—I didn't understand that was passed.

The Chairman.—Mr. Robinson of Pomona presented something like that this afternoon. Perhaps you had better read it, Mr. Secretary.

A Delegate.—I think the motion offered by Mr. Cuttle covers a different ground.. The motion passed this afternoon asks the Southern California Section of the National Irrigation Association to give their support to the same thing which we have adopted. I believe Mr. Cuttle's motion is right. I should like to see it adopted here.

The Chairman.—Would you like to hear the resolution which was passed this afternoon?

The Delegate.—I would.

(The same was then read by the secretary.)

Mr. Cuttle.—Allow me to suggest that does not provide against the pasturing of stock upon the land; does not provide for making the forest reservation a game reservation. I believe both of those are important matters.

The Chairman.—Ladies and gentlemen, you have heard the resolution offered by Mr. Cuttle and I believe it is supported. Mr. Cuttle will please put that in writing that the secretary may have it.

Mr. Boothe.—I suggest that the stenographer has it.

The Chairman.—If the stenographer has it, all right. Are you ready for the question.

(The question was then put and carried.)

Mr. Mitchell.—Mr. President, I thoroughly approve of the resolution. I don't know but that I should ask the reconsideration, for I don't think they go quite far enough. It is asking something that is for the good of all. I think the reservations should be closed to all. If you want to reforest and dont't keep it closed from the fishermen and the festive picnickers and the campers, your work will be largely undone in spite of you. They are pretty nearly as bad as a band of sheep, but not quite. Now, if we can rise to the situation and say we will give up our trip to the mountains, say, for five years and be willing to abjure the pleasure of a fishing tour and camping party or an occasional picnic, then the question is solved. I think Mr. Pinchot will meet us that far. I think he will say if you people are willing to rise to the situation and indorse this, he will close the reservation for two or for five years or long enough to allow the trees a chance to start and stop this fire business. That is one of the ways by which fires in the reservations are going to be stopped. The camper, the picnicker and the fisherman are just as bad as any other class. And our best citizens are in it. Four of the best citizens of Pomona were arrested by the forester, having left a camp fire which the law of the United States declares to be a felony, and places a fine of $5000 and two years imprisonment on the offense. Nothing was done except a trivial fine, when the forester reported them and they were brought up before the court—a little ridiculous follish fine of $10. It brought the law into contempt. Now, if we wish those laws upheald, we must be willing to help carry them out, and one of the ways to carry them out is to entirely close the reservations until such time as reforestation has had a chance. I would like a discussion of the subject and the opinion of the different ones here as to whether or not it would not be wise to pass a resolution asking, from this Water Congress, that for a five year period the reservations be entirely closed to all.

A Delegate.—Offer it.

Mr. Mitchell.—I will then, Mr. Chairman, offer a resolution to the effect that Mr. Pinchot, the forester of the United States, be requested by this congress to pass a rule that for five years the reservations of Southern California be declared closed to all.

Mr. Mills.—I take great pleasure in seconding the motion.

The Chairman.—Gentlemen, you have heard this motion made by Mr. Mitchell and seconded by Mr. Mills, that it is the sense of this congress that these reservations be closed, and that we so petition. Are you ready for the question? It is pretty drastic.

Mr. Mills.—We have listened all day to papers. We have learned that which we ought to have learned heretofore, if we haven't known of it, that our forest reservations, the reservations that feed all this vast territory that drains the vast stretch of country in which this city and others are, are being denuded of their trees. We know that the trees conserve that moisture. We may talk as we like about building dams and conserving the waters in catch basins, but if we let the trees go off the mountain tops and mountain sides, we will have no waters to catch. These trees with the roots in the soil hold them there. We must be forested. We know how other sections and other countries have fared. Mr. Mitchell gave us a picture of Palestine, and I could not but look back to the days when Joshua was sent up to the portals of Palestine, up into the land to view it, and coming back with the great bunches of grapes from the goodly land; and I could not but think of the letter that was written to me by a woman when I was coming to this country. She pictured it in all its beauty and glory, and she talked of Palestine being a land flowing with milk and honey; and she said, "California, Jim, is not only a land flowing with milk and honey, but it is a land of peaches and cream." I have often thought of Alice Heather. She lies dead in the clods of the valley.

But that day is fast coming, as Mr. Mitchell has said to you today, and I accept his authority because I have heard him before and I know whereof he speaks, that it is true—the day is fast coming when there will be no milk or honey or peaches or cream in California. We, who have staked our all in Californa, we who have married our wives and raised our children and builded our homes, we who have built our schools and built our churches, must insist upon the government, or whoever has the right through its agents, to conserve for us these waters that bring the life blood to all our valleys, that bring us our hopes, that bring us our incomes. We need drastic acton to be taken. We need not hesitate a minute about the citizen of Los Angeles or Pomona or anywhere else who wishes to go into the valley and build his camp fire beside the fishing stream. We must have drastic measures where we have to feed the mouths of our children. We must conserve these waters, and let us ask them to close these reservations that we may reforest the mountains, that we may refill our reservoirs, that we may make sure of our property for our children and their children's children, and for the thousand and hundred of thousands who come after us. Let us think of the future, of the generations that come after us, whom we may see, I trust in God, when we are beyond the Jordan, whom we may see reveling in the fruits and in the great orchards and the great properties that we have builded up. Let us today authorize drastic—that is the word you used—drastic methods to be used to save for us that which is being lost to us.

I therefore press it home upon you all that it is necessary to act. Act! Let us not talk. They say I talk, talk, talk; but God knows I act too; and let us act.

I trust you will not turn this resolution down, but that you will pass it unanimously and stand upon it with your feet that the Lord gave you.

Mr. Cuttle.—I am very much in favor of anything that will preserve the forest, but do not let us get too enthusiastic; do not let us get so far as to make the thing ridiculous. The reason that I put in my resolution that hunters should be excluded and to make it a game preserve, is that hunters go away from the routes of travel, from the houses, from the places of camping into inaccessible places in the mountains hunting game. They build their fires there and when a fire occurs it is difficult to reach it. It is not known until it is a raging conflagration. The campers in the mountains usually go to some camping place. If a fire should spring up, there is someone right there to put it out; and if we get this thing drastic, if we carry it so far, no one will pay any attention to it and it will simply kill the benefit we are seeking to derive. Let us do it cooly and deliberately if it is possible to do it. Personally I will vote against it. I don't think it is well to do it. If, after this has been carried out and the hunters are excluded, and they are made tresspassers—if then, we find it is advisable to take the other step, it may be advisable to do so. I hope it will not pass.

A Delegate.—The law at present admits miners and prospectors to the reservations. If you bar them, then you bar everyone. If you bar everyone you bar the miners and prospectors and some of the settlers who are within the United States Reservations will also come under the ban. So the motion is too far reaching. If going on the forest reservations, no one with a shot gun is allowed. You are not allowed to take a shotgun on the forest reservations, because you are much more liable to start a fire from the discharge of a shotgun than you are from a rifle. To use a rifle in the forest reservations, you have got to obtain a permit from the United States ranger of the district. Now, I have written, in former years, a good deal upon this question, and if it is admitted that everyone who is going on a forest reservation, whether for camping or hunting or whatever purpose, has to obtain a license or a permit in the district in which he is to go on that forest reservation, then you have in each district a means of knowing who is on the reservation. Then, if a fire starts, you can trace it. You know who are there and there is some way of finding out.

Mr. Boothe.—I desire to offer a substitute for the resolution—there is considerable truth in the remarks made by the last speaker; and I would offer this resolution, "That the Chief Forester of the United States be requested to take such measures as will insure the reduction of fires in the forest reservations to a minimum, and if necessary and under the law it is possible, to go even so far as to exclude persons from entering the fórest reservations for a period." That leaves the matter in such a way that it shows that we are willing to bind ourselves, that is the citizens of this part of the country, not to go in there if, under the law, all can be excluded.

Mr. Mills.—The original resolution, offered with the idea of these gentlemen tacked onto it that it be closed for five years with the exception of those who have a commission or license to go on, be he a camper, or picnicker, or anyone else, is a good thing. Exclude all except those who are duly licensed by the forest commissioner to go on.

Mr. Boothe.—Really, all we can do is to express an opinion of the desirability of having the fires reduced to a minimum by such means as the different foresters, under the law, are permitted to use. That is really the thing which they can do, and that is as far as my resolution carries it. As a matter of fact, Mr. Pinchot is quite alive to all these matters, and if he knows that the sentiment of this community will support him, he will go just as far in the direction as the law will permit him to go; and that is the reason of my resolution.

Mrs. H. W. R. Strong.—I think the matter of the destruction of the forest reservation is largely due to ignorance on the part of the people. This Congress should strive to educate the people, and teach the common people to preserve the public property. I think that will be of great value, of more value than closing the reservation. We should educate the people to look after the people's property.

I have known of people travelling along the road who would go into a grove of trees, among the dry limbs and twigs, and build a fire. Now, nothing in the world could make people do that except ignorance. This last year I have seen with my own eyes, tiny trees eight inches high taken by campers up in the forest reservation and brought home. They were perfectly delighted to show the number of varieties of trees that they had brought away from the mountains to adorn their door-yards. This is due to ignorance, and will probably continue until the people are educated to know the value of our forest reservations. In Europe you never see a sign in a public park, "Don't pick the flowers." People protect their own property. And I think it is largely a matter of ignorance that people build these fires, and the general public ought to be educated that the public property belongs to the public, and that each one has the responsibilty of taking care of it.

The Chairman.—I didn't hear any second to Mr. Boothe's substitute.

(The substitute was then seconded by several.)

(The substitute and the original motions were then read by the reporter.)

Mr. Mitchell.—I didn't intend to make this matter ridiculous and I don't think I did, Mr. Cuttle to the contrary notwithstanding. We have got to do something, and I think my motion is the best. Hunters are already excluded from the reservations. If you will read the law which Congress passed, and which the President signed on February 1st last, you will find that those classes of men, including miners, prospectors and others are mentioned. Therefore, they could not close the reservations to anybody who is permitted by law to be upon it. The resolution that I asked you to pass was only for those people that the law did not sanction. My idea was to keep out those who were going there for curiosity and not for business, and I do not think that they should be permitted to go there. Those were the ones that I was asking that the reservations be closed to.

(The substitute motion was then put by the chair and carried unaminously.)

Mr. Mills.—I move you that we instruct the Executive Committee of the National Irrigation Association to take up the matters that we have discussed and call into conference with them all boards of trade and chambers of commerce in Southern California, Los Angeles as well as the others, and to take such action as is necessary to get legislation advancing our interests along the lines here discussed today. Let us do something. Let us put something in motion.

Motion seconded.

(The motion was put and carried.)

Mr. Boothe.—I would like to offer a motion that the chairman of this meeting who is also the chairman of the committee which arranged for this Congress be thanked for this very excellent service during the getting up of this meeting and during the sessions today, and include in this motion the Secretary and I will put the motion.

(The motion was then put by Mr. Boothe and carried unanimously.)

The congress then adjourned.

Walter Mulford

Issued January 11, 1910.

U. S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE—Circular 176.
GIFFORD PINCHOT, Forester.

SURFACE CONDITIONS AND STREAM FLOW.

By

WM. L. HALL, Assistant Forester,
AND
HU MAXWELL, Expert.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1910

CONTENTS.

Page.
The tendency is toward increased floods 5
What has caused increased flood conditions? 6
  Precipitation 7
  Evaporation 7
  Temperature 8
  Topography and geology 8
  Natural and artificial reservoirs 8
  Soil 9
  Ground cover 10
The principal causes of increased floods 11
The vital part of a watershed 11
A comparative study of watershed conditions 12
A watershed where conditions have grown worse 13
A watershed where conditions have grown better 14

SURFACE CONDITIONS AND STREAM FLOW.

Popular opinion for years has been that floods are increasing in frequency and duration in many rivers of the United States. Until within a year, however, there had been no careful examination of records to see whether or not the popular opinion is based upon fact. The scientific bureaus of the Government which are directly interested in the matter had assumed that records had not been kept long enough on any river to show a change in the conditions of flow.

About a year ago it was thought worth while to look into the records to see whether any changes were discernible. The results were surprising. It was found that in many of the streams which take their rise in the Appalachian Mountains there has been a steady increase in the number and duration of floods during the past twenty or thirty years.

Following this discovery, a very general study was made of the change which has come about in the flow of a number of important rivers during the time for which records have been kept. Both the Geological Survey and the Forest Service have secured data on this subject, and the results warrant the statement that, unmistakably, floods are steadily on the increase in some of our most important rivers.[a] Particularly is this true of the rivers which rise in the eastern mountains. The increases seem to be greater on those watersheds where the condition of the surface has been the most changed. They are greatest in such streams as the Ohio, Cumberland, Wateree, and Santee, where the most forest has been destroyed, and least on the streams where forest conditions have been least changed.

It is true that in certain rivers an opposite tendency is to be seen. Floods have decreased and low waters have markedly improved. But a full inquiry into the conditions on these rivers also, as will be shown, seems to prove the rule that there is the closest kind of relationship between the surface conditions of a watershed and the flow of water through the stream which drains it.

The following table gives records regarding the flow of 10 important rivers of the United States on which careful records have been kept for periods ranging from sixteen to thirty-four years:

---

[a] Water Supply Paper 234, U. S. Geological Survey. Papers on the Conservation of Water Resources; Floods in the United States, by M. O. Leighton, Chief Hydrographer, U. S. Geological Survey.

Flood and low-water records for 10 important rivers.

CLASS I.—FLOODS INCREASED.

Name of stream.	Point of measurement.	Area of basin.	High-water stages taken in this table.	Low-water stages taken in this table.	First and second periods of record.		High-water data.						Low-water data.						Precipitation.		
					Years.	Duration.	Number of floods.	Days of floods.	Average times per year of floods.	Average days per year of floods.	Times of last period compared with first.	Days of last period compared with first.	Number of low stages.	Days of low stages.	Average times per year of low stages.	Average days per year of low stages.	Times of last period compared with first.	Days of last period compared with first.	Number of stations.	Mean (inches).	Mean annual increase or decrease (inches).
		Sq. mi.	*Ft.*	*Ft.*		*Yrs.*					*Per ct.*	*Per ct.*					*Per ct.*	*Per ct.*			
Potomac.....	Harpers Ferry, Va..	9,868	12	3	1890–1898	9	19	33	2.11	3.55	*a* 36.80	*a* 72.70	54	1,351	6.00	150.00	*a* 40.7	*a* 25.8	5	36.81	+.13
					1899–1907	9	26	57	2.77	6.33			76	1,693	8.44	188.00			5	37.97	
Monongahela	Lock 4, Pennsylvania	5,430	20	7	1886–1896	11	30	55	2.73	5.09	*a* 73.00	*a* 82.00	66	912	6.00	83.00	*a* 36.33	*a* 7.83	6	42.25	−.08
					1897–1907	11	52	100	4.73	9.09			90	979	8.17	89.00			6	41.85	
Ohio.........	Wheeling, W. Va...	23,820	22	5	1882–1894	13	46	143	3.54	11.00	*a* 28.25	*a* 31.50	79	1,333	6.08	112.50	*a* 39.00	*a* 20.75	11	41.74	−.14
					1895–1907	13	59	188	4.54	14.40			110	1,609	8.46	123.70			11	39.90	
Cumberland.	Burnside, Ky.......	8,739	25	3	1890–1898	9	32	89	3.55	9.90	*a* 34.40	*a* 14.60	61	1,261	6.77	138.00	*a* 6.50	*a* 27.00	3	46.27	−.54
					1899–1907	9	43	102	4.77	11.33			65	1,576	7.17	175.00			3	41.42	
Wateree	Camden, S. C.......	5,135	20	6	1892–1899	8	46	147	5.75	18.37	*a* 35.00	*a* 22.00	115	1,164	14.37	145.50	*b* 44.30	*b* 56.40	3	45.46	+.25
					1900–1907	8	70	187	7.75	23.50			64	508	8.00	63.50			3	47.48	
Savannah ...	Augusta, Ga........	7,300	20	6	1890–1898	9	47	116	5.22	12.77	*a* 23.40	*a* 46.50	70	566	7.70	63.00	*b* 41.00	*b* 48.00	3	48.12	−.17
					1899–1907	9	58	170	6.44	17.77			41	292	3.56	32.00			3	46.58	
Tennessee ...	Chattanooga, Tenn.	21,418	24	2	1874–1890	17	32	173	1.88	10.18	*a* 3.13	*b* 20.80	71	902	4.17	53.00	*b* 22.53	*a* 8.86	5	53.17	−.37
					1891–1907	17	33	137	1.94	8.06			55	982	3.24	57.70			5	46.83	
Allegheny...	Freeport, Pa........	9,220	16	2	1874–1890	17	39	92	2.29	5.41	*a* 35.90	*a* 42.40	99	1,747	5.82	102.70	*b* 8.10	*a* 35.00	4	41.65	−.32
					1891–1907	17	53	131	3.12	7.70			91	1,136	5.35	66.80			4	36.17	

CLASS II.—FLOODS DECREASED.

Name of stream.	Point of measurement.	Area of basin.	High-water stages taken in this table.	Low-water stages taken in this table.	Years.	Duration.	Number of floods.	Days of floods.	Average times per year of floods.	Average days per year of floods.	Times of last period compared with first.	Days of last period compared with first.	Number of low stages.	Days of low stages.	Average times per year of low stages.	Average days per year of low stages.	Times of last period compared with first.	Days of last period compared with first.	Number of stations.	Mean (inches).	Mean annual increase or decrease (inches).
Wabash	Mount Carmel, Ill..	26,300	15	3	1890–1898	9	21	351	2.33	39.00	*b* 9.50	*b* 20.50	38	1,365	4.22	152.00	*b* 15.75	*b* 15.00	5	39.54	−.40
					1899–1907	9	19	279	2.11	31.00			44	1,160	4.98	129.00			5	35.99	
Red..........	Arthur City, Tex....	40,200	20	4	1892–1899	8	19	87	2.37	10.87	*b* 16.00	*b* 30.00	49	826	6.12	103.25	*b* 83.60	*b* 74.80	5	31.80	−.24
					1900–1907	8	16	60	2.00	7.50			8	208	1.00	26.00			5	29.86	

a Increase. *b* Decrease.

THE TENDENCY IS TOWARD INCREASED FLOODS.

If the period during which the records have been taken on each of these streams be divided into two equal parts and a comparison be made of flood conditions for those parts, we find that 8 of the 10 rivers show greater floods in the last half than in the first half. The 8 rivers which show increased floods are the Potomac, at Harpers Ferry, W. Va.; the Monongahela, at Lock 4, Pennsylvania; the Ohio, at Wheeling, W. Va.; the Cumberland, at Burnside, Ky.; the Wateree, at Camden, S. C.; the Savannah, at Augusta, Ga.; the Allegheny, at Freeport, Pa.; and the Tennessee, at Chattanooga, Tenn. All of these streams, it will be noted, have their source waters in the Appalachian Mountains.

On the Potomac River, for which measurements are given for eighteen years, the number of floods during the first half of the period was 19; during the second half, 26; while the number of days of flood in the first half was 33, and in the second half, 57.

On the Monongahela River measurements are given for twenty-two years. During the first half of the period there were 30 floods; during the second half, 52. The number of days of flood during the first half of the period was 55; during the second half, 100.

On the Ohio River measurements are given for twenty-six years. During the first half of the period there were 46 floods; during the second half, 59. The number of days of flood during the first half was 143; during the second half, 188.

On the Cumberland River measurements were given for eighteen years. During the first half of the period there were 32 floods; during the second half, 43. The number of days of flood during the first half was 89; during the second half, 102.

On the Wateree River measurements have gone on for sixteen years. In the first half of the period the number of floods was 46; in the second half, 70. The number of days of flood in the first half of the period was 147; in the last half, 187.

On the Savannah River measurements have continued for eighteen years. During the first half of the period the number of floods was 47; during the second half, 58. The number of days of flood during the first period was 116; during the second half, 170.

On the Allegheny River measurements are given for thirty-four years. During the first half of the period there were 39 floods; during the second half, 53. The number of days of flood during the first half was 92; during the second half, 131.

On the Tennessee River measurements have been taken for thirty-four years. During the first half of the period there were 32 floods; during the second half, 33. The number of days of flood during the first half was 173; during the second half (in this case there was a falling-off), 137.

Mr. M. O. Leighton, chief hydrographer of the United States Geological Survey, has during the past year made an elaborate study of the floods in the Tennessee River.[a] In this study Mr. Leighton has isolated so far as possible the days of rain storm of sufficient magnitude to produce floods, and on this basis has made a comparison of the floods of the two halves of the period. Although the number of days of flood was less during the last half of the period than during the first half, Mr. Leighton shows that the precipitation decreased in an even greater degree. The results of this close analysis show that the diminution of the precipitation has been more than sufficient to account for the diminution of the floods. The natural result is that in proportion to the rainfall, floods have increased, the percentage of increase being 18.75 in the last half of the period as compared with the first half. This study is undoubtedly the most complete and authoritative that has ever been made of any American river, and it seems conclusive.

---

[a] Floods in the United States, by M. O. Leighton, chief hydrographer, U. S. Geological Survey.

The low-water stages of a river are never a safe criterion on which to judge its real condition. A slight change in the bed of a stream may considerably affect the low stage at the point where the measurements are taken, though the real condition of the stream may not be changed in the least. In the same way a stream may actually raise its bed by silting, and thus the low-water stage may be increased while the actual condition is worse than at first. A study of the low-water data of the above table shows that intensified low-water conditions as signified by the measurements do not correspond in all cases with intensified flood conditions. Of the eight streams above referred to, four show apparently intensified and four apparently ameliorated low-water conditions. But for the reasons just stated, these records can not be depended upon as having any real significance in showing the actual flow.

The constant increase in the frequency and duration of floods in these streams appears not to be due to change in precipitation. In two cases there has been a slight increase in precipitation. These are on the Potomac watershed, where, as the table shows, there has been on the average 1.16 inches more rain in the second half than in the first half of the period. On the Wateree there was an increase of 2.02. On all of the other watersheds there has been a decrease ranging from 0.90 of an inch on the Monongahela to 6.34 inches on the Tennessee. It is thus clear that while floods have greatly increased in these streams the tendency has been toward decreased precipitation.

While the record is given for only eight streams which show increased floods, it must not be understood that these are the only streams which show this tendency; rather, they are examples—particularly they are examples of streams having their source in the Appalachian Mountains. They have been given because their records are more complete and longer than those for other streams. The records of most other streams of the region, so far as they are sufficient to show a tendency, indicate the same progressive change toward increased floods. For example, this is true of the Alabama River, of the Connecticut, of the Muskingum, and of the Congaree.

WHAT HAS CAUSED INCREASED FLOOD CONDITIONS?

Since it is apparent from the records that flood conditions have greatly intensified in many streams during the past two or three decades, it is important to consider the possible causes. Several factors are known to have an important influence upon stream flow. Chief among these are climate, topography, geology, natural or artificial reservoirs, soil, and ground cover. Climate must be understood as embracing precipitation and evaporation, with whatever influences them—notably wind, humidity, temperature, and altitude. It is best to consider precipitation and evaporation separately, for they act in opposite directions and produce opposite effects.

PRECIPITATION.

It is, of course, apparent that precipitation must modify stream flow in a vital way, because no water can flow through the streams that does not first come down from the clouds. The amount of precipitation varies greatly from year to year. The amount for one year may be twice as great as for another in the same place, and at one point it may greatly exceed or fall short of that occurring a few miles away. While varying in a marked degree for short periods, precipitation becomes much more nearly constant through a long period.

If the precipitation had correspondingly increased over the Appalachian Mountain region, then it could be said that the greater and more frequent floods are due to that. But the figures which are given show that on only two of the eight watersheds mentioned in the table has there been any increase, and there by small amounts, while in the other six there has been a decrease, which in the case of one stream, the Tennessee, amounts to an average of 6 inches. The real tendency of the precipitation over these basins would therefore be to decrease flood conditions. Consequently, we must conclude that the increased flood conditions are in no degree due to precipitation.

EVAPORATION.

Taking the United States as a whole, less than half of the precipitation is said to pass through the rivers to the sea; the other part after a longer or shorter period, and after serving one purpose or another in nature's economy, goes back to the air through evaporation, except that portion which flows through underground courses to the sea.

Evaporation is fundamentally influenced by temperature, air pressure, wind, and humidity, and affects in a vital way both the regularity and amount of run-off of the streams. The Connecticut and Wateree rivers have about the same average annual precipitation—45 inches per year. Of this amount the run-off from the Connecticut watershed is 29 inches; from the Wateree watershed it is less than 18 inches. The difference is due to increased evaporation on the Wateree, where the temperature averages much higher. It is during the prolonged heated periods, which are often dry periods, that evaporation has greatest influence. It undoubtedly affects as much as any other factor the low-water stages of the streams, yet by its very nature it can not much influence floods, because they rise quickly and are never of many days' duration. There is not time for much water to evaporate. Hence we can put aside this climatic influence just as in this case we have put aside precipitation. We must look elsewhere for the cause.

TEMPERATURE.

Temperature, while influencing stream flow indirectly, through evaporation, also influences it directly. For example the upper watershed of the Monongahela River, in West Virginia, may be considered:

It is February, and there have been several weeks of cold weather; the ground, which is bare of snow, is frozen solid. There comes a heavy fall of snow, or perhaps several, bringing the snow cover to a depth of 12 to 18 inches. Within a few days the weather moderates and a prolonged rainy period follows. The first rain is caught by the snow and little escapes. But as it continues to come, it melts the snow so that the water from the snowfall and the rainfall is concentrated upon the surface at one time. If the ground were not frozen, much of it could be absorbed and distributed downward, but in the case we have assumed the earth is frozen solid, so that no water, or at least but little, can be absorbed. The whole volume is liberated on the surface and races away from the smaller streams to the larger, and at last, gathering in immense quantity, it overtaxes the channel of the main river and inundates the entire valley. It is this condition of rain, snow, and temperature operating together which brings about some of the greatest floods. A flood resulting from such a cause is not likely to occur more than once a year in any stream, and several years may pass without flood on a given watershed from this combination of causes. It can not be said that floods from this cause show any progressive change, and consequently we can not ascribe to this cause the increased flood conditions in the rivers now under consideration.

TOPOGRAPHY AND GEOLOGY.

A region's topography largely influences its run-off. Steep slopes and sharp ridges shed water quickly. A flat surface causes it to flow away more slowly.

Likewise, geology has a great deal to do with the drainage of any region. When rain has fallen and has passed through the soil cover and the soil it comes in contact with the rocks which lie beneath. In obedience to gravity it will penetrate as deeply as possible. Considering the depth to which it can go and the quantity in which it can be stored, the earth forms a great storage reservoir which tends on most watersheds to have a strong influence toward steadiness in the flow of streams. While topography and geology are important factors in considering the amount and character of run-off when one stream is compared with another, they are of no consequence when one is considering the condition in the same stream during two different periods, because they are subject to no appreciable variation. Both the topography and the geology of any given stream may be said to be constant, and so are not of importance in considering what has caused a changed condition of flow in any particular stream.

NATURAL AND ARTIFICIAL RESERVOIRS.

Some streams have on their watersheds great lakes which gather and hold immense volumes of water. A good example is the Merrimac River. On one of its important tributaries is that fine body of water, Lake Winnepesaukee; on another is Squam Lake, and, in addition, there are many smaller ones. Every natural reservoir of this kind tends to equalize the flow of the stream it feeds, because when its level is rising it is gathering in storage to pay out gradually the water which would otherwise run off at once. Moreover, on many of the lakes, especially on those in New England, dams have been built at the outlets. By this means the water of the whole surface has been increased a number of feet in depth. In dry times when it is needed this water is emptied out. A large portion is thus taken off of the crest of each flood and added to low waters. Then, too, men may construct reservoirs where there were none before. It is considered feasible in some streams to construct such extensive reservoir systems as to store a large part of the flood waters. If this can be done, the flow of the streams can be made for all practical purposes even throughout the year.

If at the headwaters of the rivers under consideration in this paper there had been great lakes or swamps which had been drained during the period under consideration, it might well be said that the influence of that action would be sufficient to cause a difference in the run-off of the streams. But, except in the case of the Wabash, there have been no changes of this character. There are on these streams no important natural lakes, and no reservoirs of great extent have been developed. Consequently, this factor also is insignificant.

SOIL.

Though the topography and geology of a watershed change too slowly to be readily observed, there are other factors in which changes may be rapid, radical, and of great importance. One such factor is soil. The soil, when considered as a factor in controlling run-off, is a complicated and delicate apparatus. It works admirably when in good condition, but it is easily deranged and is liable to severe and fundamental injury, by which its action on storm water may be lessened or almost entirely destroyed. Mistreatment frequently produces results of a serious nature in the drainage of a watershed.

The mineral soil is composed of disintegrating rock that has broken down by the slow process of weathering. Deep mineral soils, if they have not accumulated from transported materials, represent a long period of rest, during which the surface has been free from erosion, while the disintegrating rock beneath has added little by little to the depth. Upon the mineral base, and more or less mixed with it, is the humus, which owes its existence to organic matter mostly vegetable, which has decayed and added the accumulated remnants to the mineral soil. Humus vastly increases a soil's capacity to absorb and store water.

The important work which soil performs in regulating the run-off for a region is easily understood. If the soil is present in sufficient quantity and good condition, that is, is porous and well supplied with humus, it readily absorbs storm water at the surface and passes it on downward through the underlying rocks and strata. Although these rocks themselves change but little, their storage of water is regulated by the soil and varies with its changes. If the soil is hardened or removed, the amount of water which can be taken in is correspondingly reduced and the amount which is thrown off over the surface into the streams correspondingly increased. A watershed without soil or with a soil which does not readily perform its normal functions, results in erratic streams, which are usually agents of destruction rather than of use. The consideration of the flow of any stream should therefore take particular note of the soil and of the changes in its capacity for water storage.

GROUND COVER.

Scarcely separable from the soil itself is another factor of equal or greater importance in the disposition of water. This is the ground cover, or, to speak of it more particularly, the condition of the surface of the ground; that is, whether it is barren rock or clay, pasture land, cultivated land, or forest.

The condition of the surface does not influence very much, so far as known, the amount of water which falls. It is claimed by some that the precipitation is greater in the forest than on unforested land, and the figures given in the table at the beginning of this paper seem to indicate a tendency toward lessened precipitation on those watersheds which will presently be shown as having a decreased forest area. However, it is not intended at present to lay any stress upon that point. If the influence of the various factors which affect stream flow have been correctly stated, none of them is sufficient to have caused the increased floods. The natural conclusion is that the increase must be due to changes in the ground cover, or to the ground cover in conjunction with changes in the soil. Is the influence of the ground cover and of the soil sufficient to have caused the results?

It is generally agreed by those who have studied the subject most thoroughly that the forest offers the best conditions for absorption and underground storage. Next to the forest comes well-cultivated farm land; then meadow and pasture land; while the worst conditions of all are to be found on barren surfaces of stone, clay, or gravel, which because of infertility are unable to support growth of any kind.

The reasons why the forest offers the best conditions for absorption and ground storage are several. It does so, in the first place, because the foliage of the trees forms a storage place from which water drips slowly to the ground for a considerable length of time after each rain; because the complex layer of brush, leaves, weeds, mosses, and vines, all in a more or less advanced stage of decay, becomes filled with moisture with each heavy rain and holds it for a considerable time; because, also, the surplus water so stored continues to be absorbed by the upper humus-filled layers of earth; because, further, the temperature is lower and the air more humid in the forest than in the open; finally, because the snow lies there much longer. To these reasons must be added the mechanical power of the roots to go deep into the soil and break up the rocks, thus forming channels for the ready entrance of water into the earth.

On a level or slightly inclined surface a well-tilled soil may be as effective in absorbing and holding water as a forest soil. Where the slope exceeds 10 per cent, cultivation does not long go on before erosion sets in, and erosion if unchecked will remove the soil and gully the surface until all fertility has gone and all protective power is lost. Agriculture under right conditions may be an effective means of stream protection; under wrong conditions it may be the greatest menace to the even flow and usefulness of the streams.

THE PRINCIPAL CAUSES OF INCREASED FLOODS.

Undoubtedly it is the clearing away of the forest on the mountainous watersheds of the streams which have been described that has caused the great increase in frequency and duration of floods.

It is a known fact that the forests on these several watersheds have been cut away with great rapidity during the past thirty years. European conditions probably offer no parallel to the rate at which these watersheds have been cleared to make way for the rapid advance of agriculture and to supply the great manufacturing industries with the wood which they require. Forest lands, which offer the best possible conditions for soil absorption and underground storage, those great regulators of stream flow, have been changed to poorly tilled agricultural lands, which are not so good. Then these agricultural lands after a few years have been exhausted and their soil eroded into deep gullies. Finally, many of them have been turned into pasture or even entirely abandoned because they reached a condition where they could not support even a growth of grass and weeds. The best condition has been changed to the very worst condition.

Again, repeated burning of forest lands has tended to reduce the thickness and value of the ground cover and to lessen the power of the soil to absorb and to store water. The extent of damage from fire, so far as water storage is concerned, is generally vastly underestimated. A forest fire strikes both above and below the surface. It injures or kills the trees, destroys the undergrowth and brush, and consumes the great forest sponge—the ground cover and the humus. The extent of the injury is, of course, not always the same. It is sometimes slight; sometimes very great. Repeated fires tend to every kind of injury that can possibly be inflicted upon a forest soil, completely destroying the cover down to the mineral substances, and thus rendering it defenseless against the attacks of erosion. When that stage is reached, it may be depended upon that the run-off of the watershed has been profoundly affected and the regimen of the stream materially changed. The fact that forest fires have repeatedly swept over the watersheds of the streams under consideration makes it easy to believe that this factor, combined with the clearing away of the forest for agricultural purposes, has been the chief cause of the intensified flood conditions which the records now disclose.

THE VITAL PART OF A WATERSHED.

Considering the streams which drain the mountain regions, the most vital parts of the watersheds are the highest parts. It is there that precipitation is the heaviest, slopes the steepest, and the whole sum of conditions most influential. Therefore, so far as stream flow is concerned, the mountains are the portion which should be given the most judicious care. It is on the mountains that the best condition of soil and ground cover should be maintained. As the best ground cover, as has already been explained, is the forest, it is to the benefit of the streams that the mountains should be kept densely forested, in order that the conditions for the absorption and retention of moisture may be as nearly as possible ideal. Under such conditions the course of the moisture will be one of continual interference from the time it reaches the crowns of the trees till it is in the stream. Every obstruction that can be placed in the way of the water aids by that much the even flow of the rivers. Under perfect forest conditions it is well-nigh impossible for any surface run-off to take place. The rain first comes into contact with the crowns of the trees, and the drops are broken more or less into spray. Some of the intercepted water runs down the trunks or drips from the branches. That which escapes interception by the trees encounters the undergrowth and brush immediately above the ground and is intercepted and retarded. As the water continues to make its way downward the ground litter offers the next obstacle. The water is caught up by the litter, and not until this has become saturated can the water pass on. If the rain continues for some time the litter becomes filled to its capacity, and then the humus begins to absorb the water which the litter can not hold. After a time it, too, becomes saturated. The water then gradually filters into and through the underlying soil. If this is deep it stores water in large quantity and then allows the surplus to pass to still greater depths, where it finally penetrates the rock strata and replenishes the great underground reservoir, from which it emerges later as springs, some of which may be far removed, even on the opposite side of the mountain, from the place where it has come in contact with the ground. If the precipitation is in the form of snow its course is substantially the same, but with a still greater delay in passing through the litter and entering the soil. The period that may elapse between the fall of rain and the appearance of water in a river varies from minutes to months or even years.

Even with the best regulated system of checking and storing the rainfall a condition may arise where, to a large extent, the effect of obstruction and storage in a forest may temporarily be lost. Severe and prolonged freezing may result in a sheet of ice in and over the upper soil, which prevents the entrance of water, and whatever falls in the form of rain must at once run off into the streams. Many rivers experience their worst floods when their drainage basins are frozen. On account of this condition it is impossible to claim that extreme floods will not come in a stream with a forested watershed. Fortunately the condition arises but seldom.

In such cases the conditions are similar to what they would be were the covering of the soil removed. The disastrous floods which come once or twice in a generation when heavy rains descend upon snow and frozen ground would probably be duplicated or surpassed yearly, or several times a year, were the soil stripped from the mountain regions. The heavy rains of summer which now fall upon a dense vegetation and hardly affect the larger rivers would then produce destructive floods.

A COMPARATIVE STUDY OF WATERSHED CONDITIONS.

The table on a preceding page gives data regarding the flow of 10 important rivers of the United States. It has not been possible to obtain for each watershed a record of the changes which are believed to be responsible for the increased flood conditions which the record shows. It has been possible to make a detailed study of parts of the watersheds of two of the streams, the Cumberland and the Red.

A WATERSHED WHERE CONDITIONS HAVE GROWN WORSE.

The Cumberland River is a good example of how conditions have changed for the worse on some of these watersheds.

The drainage area of the Cumberland River above Burnside, Ky., comprises 3,739 square miles and lies in the heart of the Cumberland Mountains. The figures given in the table show that floods have increased in the Cumberland River at Burnside, Ky., in number from 32 in the first half to 43 in the second half, and in duration from 89 days in the first half to 102 days in the second half, while low waters have increased in times from 61 in the first half to 65 in the second half, and in days from 1.261 in the first half to 1.576 in the second half.

The removal of the forest on this watershed is progressing from three causes: (1) Clearing for agriculture; (2) lumber operations; (3) fires.

In 1890, when these measurements were begun, 21 per cent of the watershed above Burnside was cleared; in 1908 the cleared area had grown to 32 per cent. During the eight years from 1900 to 1908 clearing of forest for agricultural purposes went on on this watershed at the average rate of five-eighths of 1 per cent per year.

The total stand of timber on this part of the Cumberland watershed is 6,212,531,000 board feet. It is being cut away by lumbering alone at the rate of 4 per cent a year. These figures show that timber is disappearing on account of lumber operations eight times as fast as it is removed to clear land for farming purposes. In other words, supposing that lumbermen would cut clear as they go, 8 acres would be stripped for timber to 1 cleared for agriculture. The forest is not being cut clear. Instead, the lumberman is going over it time after time, picking out the particular kinds or classes of timber that he wants. First, he took the walnut and cherry; next, the white oak and poplar; now he is taking the chestnut and other kinds of oak. At the present time few tracts can be found from which one or more of the valuable timbers have not been culled. Other tracts have been stripped of nearly their entire growth.

At intervals of from one to five or six years fires run through the woods on the hills and mountains where the Cumberland River has its source. The fires are more frequent and destructive in districts where part of the timber has been cut and the refuse left on the ground. The dry ridges burn oftener than the coves, because the latter are sometimes too damp for burning. In times of prolonged drought, however, fires run through the ravines and coves where the densest growth is found. The fires are usually slow, and the damage to mature timber is not great, but the injury to the young growth is frequently excessive, and soil damage is serious. As a rule all seedlings and sprouts less than 4 or 5 feet high are killed, and, since fires come at intervals so frequent that the young growth can not attain a size above that, a large part of what would be the future forest, as well as the present ground cover, is destroyed. The surviving stand thus becomes thinner year by year, since it can not be replenished by young growth, and since the mature trees are steadily falling by natural decay or by the ax.

Though the fires are slow and small, they burn the leaf cover and the upper layers of humus at each visitation. This removes or injures the porous surface, one of whose essential functions is to arrest the storm water falling upon the slopes and afford it an opportunity to sink into the ground. With the packing of the surface, after the litter and humus have been burned away, the water flows down the slopes and quickly reaches the streams, where, if in sufficient quantity, it produces flood conditions. Low water follows, because the hard ground is able to take in but little of the storm water to be paid out slowly afterward.[a]

The behavior of the Cumberland River shows a direct and positive relation between the run-off and the changed condition of the surface. The changes due to agriculture and lumbering can be definitely stated, but the extent and effect of forest fires are not subject to exact calculation. Yet undoubtedly all of these influences are active in producing the results as shown in the flood and low water records at Burnside. It is impossible that these results should be due to rainfall, because the rainfall was approximately 10 per cent less in the second half of the period. Since no other influences could have produced the result, there is no conclusion possible other than that the progressive floods and low waters have been due to the changes accomplished on the surface of the watershed.

A WATERSHED WHERE CONDITIONS HAVE GROWN BETTER.

The fact that man by his operations may decidedly change the regimen of a river is shown not alone by those streams whose flow has been influenced by clearing away the forest. It is shown, on the other hand, by streams whose watersheds of prairie soil compacted for ages by the trampling of buffalo, and more recently by cattle of the great ranches of the West, have been to a large extent brought under cultivation.

---

[a] A more definite statement regarding the damage to humus by fire may be made for the upper watershed of the Potomac River. In Water-Supply Paper, No. 192, the U. S. Geological Survey shows that 838 square miles of the forest of this watershed had been so severely burned by repeated fires as to completely or almost completely destroy the humus. Other tracts aggregating twice that area had their soil severely damaged, but not to the point of complete destruction of the humus. Considered together, these burned-over lands have an area of over 2,500 square miles, or 27 per cent of the drainage basin above the point of measurement. Assuming that the humus of the uninjured forest soil of the Potomac basin would hold back for absorption 2 inches of water, and assuming that with the humus damaged as in this case the capacity of the soil for receiving water is lessened one-half, then 1 inch will be held instead of 2 inches, as formerly. In an area of 2,500 square miles, the inch of water, which formerly was absorbed but now flows away quickly, amounts to about 6,000,000,000 feet. During a heavy rain that quantity of water in excess of what would flow off quickly before would go at once to the streams.

The rating table for the Potomac at Point of Rocks, where the measurements were made, shows that when the river is at a 10-foot stage 61,000 cubic feet of water pass per second. The 6,000,000,000 cubic feet of extra flood water from the burnt forest is therefore sufficient, without a gallon from other parts of the basin, to maintain a 10-foot stage at Point of Rocks for thirty hours. The effect on succeeding low-water stages is a logical one. There is simply 6,000,000,000 cubic feet less of stored water to come gradually after the rains cease.

A stream which shows this tendency in an unmistakable way is the Red River, which forms the boundary for many miles between Texas and Oklahoma. On this stream records of flow are available for sixteen years. The number of floods in the first half of this period was 19; in the second half, 16. The number of days of flood in the first half was 87; in the second half, 60. Considering also the low-water periods of this river, we find that in the first half of the period there were 49 periods of low water; in the second half there were 8. In the first half the duration of low water was 826 days; in the second half, 208 days. A falling off in the rainfall occurred on this watershed, there being 1.94 inches less water per year in the second than in the first. Its drainage basin is, and has been during the time of its known history, practically without forests, only 1 acre in 10 being forested. In that respect it differs from all eastern and many western rivers whose basins are more extensively forest covered.

Why has the Red River constantly changed its flow toward steadiness and uniformity, while many other rivers have changed in exactly the opposite direction? The area of the Red River drainage basin above Arthur City, Tex., where the records were made, is 40,200 square miles, divided almost equally between Oklahoma and Texas. In this river, as in those before mentioned, the geology and topography have not changed. The precipitation has changed considerably in the direction of lessened rainfall, but not enough to account for the record. In soil conditions, and especially in the condition of the surface, however, the change has been marked. At the beginning of the period of measurement, in 1890, the country was for the most part occupied by large ranches. The native prairie sod had never been broken up.

On the part of the watershed lying in Texas there had been some settlement at an early date, but as late as 1900 no more than 12 per cent of the Texas part of the watershed had been improved. In the Oklahoma part of the basin, in the same year, the improved portion was 16 per cent. Development began most extensively about 1900. In southwestern Oklahoma, in that portion drained by the Red River, it was stimulated by the opening of Indian reservations to settlement. The Cheyenne, the Arapahoe, and the Wichita lands were opened, it is true, in 1890, but the real opening of the country to settlers came in 1901, when the Comanche, the Apache, and other Indian lands were opened, aggregating over 10,000 square miles, or more than one-fourth of the entire Red River basin above Arthur City. Another tract of over 8,000 square miles, the Choctaw and Chickasaw lands, began its development about the same time. A summary of these figures shows that in 1908 the Red River basin in Oklahoma had 10,200 square miles of improved land, instead of 3,284 square miles in 1900. Statistics are not complete for the Texas portion of this basin but the Texas portion has developed at about the same rate as the Oklahoma part. It is probable that the whole Red River basin above Arthur City, in Texas and Oklahoma, had 40 per cent of its land under improvement in 1908, instead of 14 per cent eight years earlier.

The results which have appeared in the form of change of the flow in the Red River are precisely what ought to be expected from the changes in surface conditions. Theoretically, such results should appear, and as a matter of fact, they have appeared. The hardened prairie soil has been broken up and changed into cultivated fields over 40 per cent of the area, and thereby the absorptive capacity of the soil has been much increased. Over the remainder prairie fires have been kept out and better growth of grass secured. The extensions of cultivation and the improvement of the grass land has tended to equalize the flow of this river. The river's behavior has become better as the area of wild land has decreased. In other words,—wild, barren land, being the worst condition for the protection of a watershed, and cultivated farm lands being next to forests the best condition, the change of a large part of the watershed from the worst condition to the next to the best condition has brought about this result.

The same law is thus seen to work on both the Cumberland and the Red River watersheds, but in different directions. On the Cumberland, as the watershed changes from the forest (the best condition for stream protection) to farm land, to pasture land, and even to barren condition (the very worst condition for absorption), the flow of the river is made more extreme, both as to floods and low waters. On the Red River watershed, beginning with a wild, almost barren, compacted surface, cultivation has changed the condition to that of permeable farm lands, which, next to forests, offer the best conditions. These two extremes exemplify, therefore, in different directions, the working of the same law—that there is a vital relation between the condition of the surface of the watershed and the manner of flow of the stream which drains it.

Approved:

JAMES WILSON, *Secretary of Agriculture.*

WASHINGTON, D. C., *November 26, 1909.*

[Cir. 176]

O

Walter Mulford

Issued March 7, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—Circular 143.

GIFFORD PINCHOT, Forester.

(IN COOPERATION WITH THE DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY, GEORGE OTIS SMITH, DIRECTOR.)

THE RELATION OF THE SOUTHERN APPALACHIAN MOUNTAINS TO INLAND WATER NAVIGATION.

By

M. O. LEIGHTON AND A. H. HORTON,
U. S. GEOLOGICAL SURVEY.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1908

On March 4, 1907, Congress passed the following provision in connection with the Agricultural appropriation bill:

> *Survey of and report on Appalachian and White Mountain watersheds.*—To enable the Secretary of Agriculture to examine, survey, and ascertain the natural conditions of the watersheds at and near the sources of the various rivers having their sources in the Southern Appalachian Mountains and the White Mountains, and to report to Congress the area and natural conditions of said watersheds, the price at which the same can be purchased by the Government, and the advisability of the Government purchasing and setting apart the same as national forest reserves for the purpose of conserving and regulating the water supply and flow of said streams in the interest of agriculture, water power, and navigation * * *.

Because of its identification with studies of stream flow and its facilities for stream measurement arrangement was made with the Geological Survey for a study of the water resources of the Southern Appalachian Mountains. The following report on The Relation of the Southern Appalachian Mountains to Inland Water Navigation has resulted from that study.

CONTENTS.

Page.

Introduction 5
Rivers which drain into the Atlantic 8
  Potomac and James 9
  Roanoke 11
  Great Pedee 14
    Yadkin 14
  Santee 17
    Wateree 17
  Savannah 18
  Altamaha 21
    Oconee 21
  Chattahoochee 22
Rivers which drain into the Ohio 24
  Monongahela 24
    Youghiogheny 27
  Kanawha 29
  Tennessee 32
    First section: Above Chattanooga 32
    Second section: Between Chattanooga and Riverton 32
    Third section: From Riverton to Paducah 33
The Ohio 35
Conclusion 37

THE RELATION OF THE SOUTHERN APPALACHIAN MOUNTAINS TO INLAND WATER NAVIGATION.

INTRODUCTION.

The United States had up to June 30, 1905, expended nearly $30,000,000 to improve navigation in rivers that have their upland sources in the Southern Appalachian Mountains. Including the Ohio River, which is so largely supplied with water from this mountain area, the total expenditure amounted to more than $36,000,000. With this expenditure freight shipments over these rivers amounted in the year 1905 to 14,614,781 tons, together with 196,000,000 feet B.M. of lumber. The projects for improvement authorized by Congress on these rivers are not yet complete. On some of them, indeed, the work has hardly commenced. When finished the cost, excluding improvements on the Ohio proper, will be more than $56,000,000, according to present estimates.

The reason for this relatively small amount of traffic compared with the large expenditure lies in the fact that under present conditions the rivers fail to provide a depth of water throughout the year sufficient for navigation. There are seasons of high water in which deep-draft vessels may pass readily up and down these rivers with open navigation and plenty of water under the keel. This is in the high tide of the year when the rivers are glutted with rain or melted snow shed by prodigal hills and mountains, and when they carry millions of tons of sediment eroded from the cleared mountain slopes. It is a period of short duration, always followed by weeks of privation, when the sediment has been deposited and the rivers are in need of the water that they have so ruthlessly wasted. It is this condition of alternating silt-bearing floods and low water that makes it necessary for the Government to expend millions—first, to provide depth of channel sufficient for navigation, and, second, to remove deposited detritus in order that the depth of channel may be maintained.

The chief obstacles to navigation, then, are lack of water during portions of the year, and detritus which is washed into the streams and which gradually fills the channels or forms obstructions at the mouth. Were the flow uniform, the amount of water carried by a river during the year would be sufficient to provide a good depth at all times. But the flow is uneven; there is too much water at one time and not enough at another. The floods of the spring waste the water which should be available to maintain a navigable depth during summer and fall. To lessen this inequality of flow should therefore be the aim of all measures for the development of our waterways. If the rivers could be kept always in gentle flood a relatively small expenditure for reservoirs, locks, and dams would be required. In the same way, if means could be found to prevent silt and sand from being washed into the streams the enormous cost of dredging would be largely done away with.

One factor which tends to make the flow of streams uneven is the unevenness of the rainfall. Rain comes at irregular intervals and varies in intensity. In consequence, the amount of water which in different seasons runs off the land into the rivers varies also. Yet there are natural factors through which a part at least of this variability may be overcome. Among the most important of these is the vegetation which covers the slopes upon which the rain falls. In itself, and in the effect which it has upon the soil, it causes the water to be fed gradually into the streams, and so tends to bring about a uniform flow. The amount of surface soil which is washed from bare slopes in the Southern Appalachians is enormous. Not only does growth upon the slopes tend to keep the flow even, but it is also the chief agent in preventing erosion. Therefore, a single factor comes to relieve both conditions which threaten the navigability of streams.

Though the principle of action of vegetation is the same, no matter what the form of vegetation is, the degree of efficiency differs radically. Without question, the forest, of all forms of vegetable growth, is the most efficient in conserving the rainfall and preventing erosion. It keeps the soil in a loose condition, covers the ground with a litter of leaves and branches, and protects the ground surface from the direct rays of the sun and from the full force of rains, all of which is of the highest importance in checking sudden run-off. The leaf canopy overhead breaks the force of heavy rains and allows the water to reach the ground gently and not faster than it can be absorbed. Moreover, the decay of roots and the presence of leaf litter keep the soil porous and capable of absorbing a greater amount of water than when it is bare. The capacity of soil to absorb heavy rainfall such as that of the Southern Appalachians depends largely upon its porosity. In this connection the leaf canopy also plays an important part, since it protects the soil from the rays of the sun which tend to harden the surface and so destroy its absorptive qualities. Forest soil is capable of absorbing a rainfall of several inches with comparatively little run-off, and the water thus absorbed passes to ground storage, to pass off later through springs in seasons when rainfall is lacking. A soil depleted of humus and exposed to heavy rains hardens in structure and erodes rapidly, a condition which is as unfavorable to the maintenance of navigable streams channels as violent fluctuations in the flow.

The Southern Appalachian forests act as a great storage reservoir, and this is done largely through the medium of its humus, the litter of decomposing vegetable matter which forms the forest floor. It is this which acts like a sponge to absorb the water as it falls. The lowest estimate of the storage capacity of humus made by Ebermayer places it at considerably more than its own weight; and Wiley, from his investigation of Florida muck, gives it about the same capacity, while Wollny, as substantiated by Henry[a] in his laboratory experiments, places it at about four times its own weight. The capacity of humus to absorb moisture depends, moreover, upon its origin. That from hardwoods and spruce has a greater capacity than that from pines. In the actual amount of water absorbed, also, hardwood humus surpasses that of most conifers, since it is deeper. The Appalachian forests are composed largely of hardwoods, and under proper management humus is accumulated to a great depth. At present, frequent fires have in many places reduced or even destroyed it, while excessive cutting of timber has further tended to deplete it by exposing it to the sun and wind.

Though the influence of the forest in promoting the absorption of rain is great, it is even more apparent in the case of snowfall. A large proportion of the winter and early spring precipitation in the Southern Appalachians is in the form of snow. It takes from one day to two weeks longer for this to melt beneath the forest than on fields and pastures. In consequence, the danger from floods through sudden melting is lessened. The tendency is for the snow when it melts to be absorbed by the forest soil and to pass gradually to the streams through subterranean drainage.

The function of the forest and of the humus beneath as a storage reservoir is of high importance, yet in relation to navigation and the storage of storm waters the influence which the forest has in checking erosion is of equal, if not of greater, value. There are few rivers south of Pennsylvania in which sand and silt bars have not been formed by detritus washed from tilled slopes. In the Southern Appalachians, as the population increases and as tilled land on the lower and gentler slopes is destroyed by washing, the steeper slopes are being cleared for farming. Since erosion increases with the slope, this will in the future result in even more rapid erosion with a corresponding increase in the silt burden of the streams. Even on the lesser slopes the erosion from the cultivated heavy red clays and friable loams of the Southern Appalachians is very great. These conditions, therefore, make it absolutely necessary to protect the forest cover at the sources of all streams if the rivers of the region are to be kept navigable.

---

[a] Revue des eaux et forêts, 1904, pp. 353 et seq.

The system of channel adjustment which has been largely used in this country to maintain the navigability of rivers has in many cases accomplished great good. It entails, however, an enormous expenditure of money, both in original cost and in cost of maintenance, and, besides, it neither regulates the water supply nor checks erosion. Unquestionably, the method of adjustment by conservation, which has been extensively used in Russia and in France, and partially installed at the head of the Mississippi, will be adopted generally in the United States. This method provides for reservoirs which fill in the spring-freshet season to increase the flow later in the year in time of drought. Floods are checked and sufficient water for navigation at all seasons is provided. By itself, this method would give excellent results in regions where erosion is not a factor. Yet in France it has been found by experience that in mountainous regions the reservoirs gathering water from denuded watersheds become clogged with sand, silt, and gravel and are thus made useless. In the Southern Appalachians this method could succeed in practice only where erosion is prevented by the retention of the forest cover. Erosion inevitably destroys reservoirs and must be checked if the reservoir method is to be effective.

In the storage of water and the equalization of stream flow engineering works will be necessary to cope with the amount of excess water which the forest can not be expected to control, but neither the forest alone nor engineering works alone are sufficient in all cases. The reservoir method depends for its efficiency upon the forest, and without it can not be considered. With the mountain slopes under protection, a system of storage reservoirs properly constructed and controlled would have an almost incalculable effect upon the permanent navigability of the rivers of the Southern Appalachian region.

This report contains the results of a study of most of the navigable rivers of the Southern Appalachian region, and discusses the effect which a system of reservoirs and the preservation of the forest cover would have upon the navigability and general value of these streams.

RIVERS WHICH DRAIN INTO THE ATLANTIC.

The navigable rivers rising in the Southern Appalachian Mountains and covered by this report may be divided into two general systems—those which discharge along the Atlantic coast, and those which discharge into the Ohio River. The first includes the Potomac, James, Roanoke, Great Pedee, Santee, Savannah, Altamaha, and Chattahoochee; the second includes the Monongahela, Kanawha, Little Kanawha, Big Sandy, Kentucky, Cumberland, and Tennessee. The coast rivers are considered first.

POTOMAC AND JAMES RIVERS.

The Potomac and James rivers are both tidal to their heads of navigation. In the former Little Falls, just above Washington, effectively bars navigation. In the latter similar conditions exist at Richmond. In each case the mean range of tide at the foot of these falls is about 3 feet. In each there is generally a good depth in the tidal estuary and the benefits derived from the delivery of a large quantity of water during the low-water season are by no means so pronounced as in those navigable portions of rivers to which the tide does not ascend. There is, nevertheless, a well-defined benefit. Channels in tidal estuaries, properly dredged to desired depths, would generally be fairly permanent and of low maintenance cost were it not for material brought down in suspension from the upper drainage area during freshets and deposited in the channels. The increased flow of water scours out the channel at certain places, but freshets of this character generally distribute their disadvantages equally with their benefits. Whenever they scour out one section of channel to the benefit of navigation they also deposit a large amount of material in some other section to its disadvantage. Providing means for storing floods reduces this torrential flow and thereby diminishes and possibly holds back altogether that part of the material that is so injurious to navigable channels in tidal estuaries. The following statement in reference to the James River appears in the Report of the Chief of Engineers, U. S. Army, for the year 1885, Part 2, page 947:

> It has been estimated that at least 275,000 cubic yards of solid matter pass Rocketts Reef in twenty-four hours when there is a freshet not higher than 10 feet. No account is taken in this estimate of the heavy material rolling along the bottom. It is probably far within limits to say that in such a freshet not less than 300,000 cubic yards pass in twenty-four hours. Large quantities of the lighter particles held in suspension are carried far down the river, but the heavier pieces that roll along the bottom move only by a rapid current and stop as soon as the freshet subsides and must be taken out by dredging. It is therefore believed that it will be necessary in the future as it has been in the past to keep on hand a dredging plant ready for emergencies.

This is a significant statement. It means that, year after year, the expense of maintaining and operating a dredging plant must be kept up in connection with James River navigation, and while the cost in any single year may not appear great, a succession of years will produce a total expense far in excess of the cost of providing reservoir capacity sufficient to prevent the silting up of the lower channel. Up to July 1, 1905, the Government had expended in round numbers $1,350,000 on the James River, and the total estimate for the finished improvement of that river is $5,375,000. But, even with this expenditure, high maintenance charges will continue so long as freshets continue to bring down material that must be dredged from the navigable channel. The same is true of the Potomac River. The conditions upon the drainage areas of both rivers with reference to the possibilities of water conservation may be summarized as follows:

In the Potomac basin, topographic surveys reveal 6 reservoir sites of sufficient capacity for the storage of the entire annual discharge from 1,350 square miles. That is, if these reservoirs were constructed and the gates closed, a year would pass before the water would spill over the tops. These reservoirs would thus place under control 12 per cent of the entire drainage area of the Potomac above Great Falls. Many other reservoir sites might be designated on more careful survey. The total capacity of these reservoirs is 58,510,000,000 cubic feet. The facts concerning them are given in Table 1:

TABLE 1.—*Selected reservoir sites in the Potomac River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
North Fork, South Branch, Potomac River at Petersburg, W. Va.	460	1.12	520	18,550	460	134	7,600
North Fork, South Branch, Shenandoah River, Rockingham County, Va.	210	.84	180	6,910	210	92	3,410
North River, Rockingham County, Va.	290	1.33	390	14,150	290	96	9,710
Middle River, Augusta County, Va.	180	1.33	240	6,190	140	100	4,250
South Fork, Shenandoah River, Rockingham County, Va.	500	1.42	710	2,290	50	40	3,930
Do.	200	1.42	280	10,420	200	95	7,150

Similar examination of the James River basin discloses 7 reservoir sites of a capacity sufficient to permit the storage of the mean annual discharge from 2,130 square miles, or 31 per cent of the entire drainage area above Richmond. The facts concerning these reservoirs are given in Table 2:

TABLE 2.—*Selected reservoir sites in the James River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Jackson River, West Bath County, Va.	300	1.18	350	12,400	300	124	5,100
Cowpasture River, Bath County, Va.	280	1.18	330	10,700	280	118	4,200
North River, Rockbridge County, Va.	210	1.18	250	8,620	210	137	5,440
Calfpasture River, southwest Augusta County, Va.	120	1.18	140	4,140	110	100	2,650
James River, Botetourt County, Va.	1,060	1.18	1,250	43,890	1,060	135	18,470
Buffalo Creek, Rockbridge County, Va.	80	1.18	90	3,660	80	118	1,960
Johns Creek, Newcastle, Va.	90	1.18	110	4,620	90	123	3,120

The practical effect of these reservoirs upon navigation in the Potomac and James rivers would be a decrease of 12 per cent in the floods of the Potomac and of 31 per cent in those of the James. As it is the high part of the flood that accomplishes the greatest amount of erosion, it is apparent that the amount of sediment to be taken care of would be decreased by a far greater percentage than the decrease in the height of the floods.

ROANOKE RIVER.

The use of the Roanoke River for navigation fluctuates widely from year to year. Up to June 30, 1905, the United States had expended in the improvement of this river $239,351.75, but the work done has not been effectual in inducing shippers to make extensive use of the channel for transportation. The channel is too precarious to warrant the establishment and maintenance of transportation lines. The Report of the Chief of Engineers, U. S. Army, for 1897, states that only two steamers were plying during the year and that apparently the commerce was rapidly decreasing, inasmuch as eight steamers were making regular trips in 1894.

The Roanoke River flows into the extreme westerly end of Albemarle Sound. The distance from the mouth of the Roanoke to the ocean is 108 miles, and the controlling depth of water 7½ feet. From the mouth of the river up 67 miles to Indian Island Bar the channel at low-water stages exceeds 8 feet in depth. At this bar the depth is diminished from 15 feet to less than 5 feet. Thence, 62 miles to Weldon, the channel is a succession of pools separated by bars of sand, gravel, or rock. The project for improvement contemplates a channel from Hamilton to Weldon, with a width of at least 50 feet and 5 feet deep. The river is subject to frequent and sudden freshets causing recorded rises of 50 feet at Weldon. But during dry seasons the maintenance of a 4-foot channel below Weldon can hardly be accomplished without a greater supply of water. If this were provided, it would secure even a greater low-water depth and would bring about the adjustment of all the navigation difficulties in the river. It should be remembered that a 4-foot channel will not, under modern traffic conditions, permit the passage of boats sufficiently large to compete with railroad transportation. Small shipments are no longer profitable by the water route and therefore a 4-foot channel in the Roanoke would hardly be worth while even if it were properly maintained. Can an extra depth be provided from storage?

Examination of the drainage area shows 4 available reservoir sites of a capacity sufficient to store the mean annual run-off from 1,250 square miles. The facts concerning these reservoirs are set forth in Table 3:

TABLE 3.—*Selected reservoir sites in the Roanoke River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
North Fork, Roanoke River, east Montgomery County, Va.	120	1.23	150	4,820	120	125	2,170
South Fork, Roanoke River, southeast Montgomery County, Va.	110	1.23	140	4,600	110	140	1,790
Goose Creek, Bedford County, Va.	260	1.23	320	10,200	260	106	6,560
Roanoke River, Bedford County Va.	760	1.23	930	29,700	760	150	15,000

The records of the United States Geological Survey, made at its gauging station on the Roanoke River at Neal, N. C., show that the average low-water flow is about 3,000 cubic feet per second. With the run-off from the 1,250 square miles excluded, the ordinary low-water flow at Neal would be 2,600 cubic feet per second. This discharge corresponds to a gauge height of about 2 feet. One of the results of the work of the Geological Survey at Neal, N. C., was the establishment of a rating table for this section of the Roanoke, which shows the amount of water flowing in the channel at each stage of the river from lowest to highest. Therefore, if to the observed flow of the river a certain additional quantity is to be added it is merely necessary to add the additional quantity to the observed flow and consult the rating table to find the height or stage of the river corresponding to the sum of these two. For example, if the Roanoke at Neal is discharging 1,920 cubic feet per second the stage of the river is 1 foot on the United States Geological Survey gauge. Similarly, if 2,580 cubic feet per second are passing through the channel the river is at the 2-foot stage; when the gauge reads 3 feet, 3,280 cubic feet are passing by Neal each second, and so on.

Taking the river at ordinary low stage, the problem is to determine how the stage of the river can be increased by the proper manipulation of the reservoirs above described. Table 4 gives in tabular form the number of days during which the reservoirs would be able to increase the stage of the river to various heights from 1 to 8 feet, the calculations being based upon full, three-quarters-full, and half-full reservoirs.

TABLE 4.—*Roanoke River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cu. ft. per sec.*	*Days.*	*Days.*	*Days.*
1	700	800	600	400
2	1,400	402	302	201
3	2,100	268	201	134
4	2,856	197	148	98
5	3,650	154	115	77
6	4,620	122	92	61
7	5,620	100	75	50
8	6,700	84	63	42

The practical use of this table may be illustrated as follows: With full reservoirs the stage at Neal could be permanently maintained 1 foot higher than low-water flow for a period of eight hundred days. Of course, the river does not remain at the low-water stage for that period of time and therefore some more useful depth could be arranged. The table shows that an additional stage of 4 feet could be maintained for one hundred and ninety-seven days. But this is also an unnecessarily long time. It is found on consultation of the record for the Roanoke that about one hundred and twenty days is the maximum low-water period. This does not mean that the river stays at low water during that entire period. On the contrary, the fluctuations are generally above this stage. But, for the sake of a conservative estimate we will assume a constant low water during the period. A glance at the table will show that with reservoirs full an increase of 6 feet over the low-water stage could be maintained for a period of one hundred and twenty-two days. That is, during this period the river at Neal could be maintained 6 feet higher with the reservoirs than without them.

It might be that in years of little rain the reservoirs would not be filled, but the year would be most exceptional in which they would not receive sufficient drainage for three-quarters of their capacity. Considering the matter on this basis, then, the table shows that an additional stage of 5 feet could be maintained for a period of one hundred and fifteen days, or almost the entire low-water period assumed.

Considering now the very exceptional year, when we will assume that the reservoirs are only half full, it is seen from the table that an additional stage of 3 feet could be maintained for a period of one hundred and thirty-four days or considerably longer than the assumed low-water period, or a stage of 4 feet could be maintained for a period of ninety-eight days.

The remarkable showing made by these estimates will be appreciated by those who are familiar with river navigation, its requirements, and difficulties. To provide an additional stage of 6 feet on a river for one hundred and twenty-two days during the low-water season is practically to make the river over, and in the case of the Roanoke it is to change it from a river of shallow and precarious navigation to one in which navigation possibilities will meet all reasonable demands. All this benefit arises from the construction of reservoirs; but it should be remembered in this connection that the benefits to navigation constitute merely one of the advantages arising from the construction of the reservoir system.

Lest anyone unfamiliar with the situation should be deceived, there are certain statements which should be made with reference to the table given above. The additional river stages that will be secured by the discharge of definite amounts of water from storage reservoirs refer to the cross-section at Neal, N. C., alone, except for those places along the river in which the slope and channel capacity are the same as those at Neal. The channel varies in slope and capacity, and, as these increase, a given amount of water will have less effect in adding to the stage of the river; and conversely, as the slope and capacity decrease, the effect of a given amount of water upon the gauge height will be greater. A thorough survey of the channel of the Roanoke River would be necessary in order to determine the effect upon the gauge height at each point in the river, but such information is not necessary in the present broad treatment of the subject. The pilot of a steamboat along a river managed as described above would be thoroughly familiar with the conditions. A given gauge height at Neal or at any point along the stream would indicate to him the depth of water along all the crossings.

In the manipulation of the reservoir system to secure additional navigable depth, the results would be secured through a similarly practical attitude toward the subject. Details are aside from the purpose of this paper. The great point is that the construction of this reservoir system will so increase the value of the Roanoke River as a means of transportation that the cost of the system reckoned upon the most liberal basis will in no wise be commensurate with the benefits conferred.

GREAT PEDEE RIVER.

Navigation on the Great Pedee River will be benefited by the establishment of the proposed National Forest through its principal tributary, the Yadkin, the headwaters of which lie within the area under consideration. Improvements for the benefit of navigation on the Yadkin itself were abandoned by the Government after the expenditure of $102,886, because it was discovered that the portion of the river that had been under improvement was above "another stretch of much more difficult character where the declivity was so great that its improvement for boats of any character could be accomplished only at very great expense and entirely out of proportion to the benefits." (Report of Chief of Engineers, U. S. Army, 1892, Vol. 2, p. 1435.)

On the Great Pedee itself a depth of 8 feet extends from the mouth of the river to Smiths Mills, a distance of 52 miles. Above this the present project contemplates a channel of 3½ feet to Cheraw, the head of navigation, 172 miles above the mouth. The total expenditure by the Government on the Great Pedee up to June 30, 1905, was $157,460. It is estimated that the project when completed will cost $245,300. Inward freight consists chiefly of general merchandise and fertilizers, and outward freight of rosin, turpentine, tar, cotton, cross-ties, and lumber products, together with rice. In 1904 the tonnage on the river was 162,566, with a value of $1,507,181. According to the records there has been a very general increase in traffic since 1891, especially in the 8-foot channel below Smiths Mills.

The projected depth of not less than 3½ feet at low-water stages from Smiths Mills to Cheraw has not yet been accomplished. Even if it had been, it is difficult to show whence any great benefit would arise. Under present conditions of transportation, boats drawing only from 3 to 3½ feet are of little value as carriers. They can not compete with the poorest kind of railroad transportation. Therefore the expenditure of money along this river to secure merely a 3½-foot stage at low water would seem to be little better than a waste of Government funds. Yet it appears impossible with the present wide range of river stages to secure a greater depth without enormously disproportionate expense, because during low-water periods there is not enough water to produce the desired stage. This is one of the cases in which the extreme value of conserved water, held back during flood seasons in reservoirs in the uplands and judiciously released during low-water seasons, may be appreciated. On the Upper Yadkin River a preliminary survey has revealed many reservoir sites, of which 5 have been selected for the estimates in this paper. The details concerning these reservoirs are given in Table 5:

.TABLE 5.—*Selected reservoir sites in the Yadkin River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Yadkin River, Wilkesboro, N. C.	500	2.72	1,360	42,050	480	130	22,600
Yadkin River, above Wilkesboro, N. C.	230	2.72	620	20,300	230	140	10,100
South Yadkin River, Davie County, N. C.	730	2.72	2,000	20,500	230	80	15,600
Deep Creek, Yadkinville, N. C.	120	2.72	330	9,400	110	100	6,600
Ararat River, Surrey County, N. C.	290	2.72	790	5,300	60	100	3,700

It is proposed to show in a manner similar to that already pursued with reference to the Roanoke what may be accomplished by proper reservoir manipulation on the Great Pedee. The discussion is based on the rating table at the cross section of the Yadkin River at Salisbury, N. C., where the Geological Survey has for many years maintained a gauging station. This point is considerably above the head of navigation, and therefore the data can not be applied directly to the navigable part of the river. Unfortunately there is no record of gaugings on the Great Pedee River sufficiently long or comprehensive to serve as the basis of a rating table. The effect of the discharge from reservoirs on the gauge height of the section at Salisbury is not as pronounced as it would be on the lower navigable portion of the river, because of the steep slope along the Salisbury section. Therefore the results, as shown by the following table, are far less favorable to the reservoir proposition than they would be if applied directly to some section in the flatter navigable portion.

The following statement is similar to that previously given with reference to the Roanoke and is subject to the same interpretations: Ordinary low-water flow, 2,000 cubic feet per second; adjusted low-water flow with reservoir area excluded, 1,350 cubic feet per second, equivalent to gauge height at Salisbury of 1.3.

TABLE 6.—*Yadkin River at Salisbury.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	1,970	560	420	280
2	4,940	223	167	112
3	8,210	134	100	67
4	11,450	96	72	48

Table 6 shows in general that with full reservoirs there is plenty of water to maintain an added 3-foot stage for an assumed dry weather season of more than four months, or with reservoirs three-fourths full, for an additional 3 feet for more than three months. The effect on the navigable portion of the Great Pedee between Cheraw and Smiths Mills would undoubtedly be more pronounced than this, but, assuming it to be the same, there would be an assurance of a continuous 6-foot stage along this portion of the river instead of the precarious 3 feet now available. A 6-foot channel would probably fulfill all the demands for navigation in this part of the country and allow the region to develop its transportation facilities to an extent commensurate with its wealth and importance.

SANTEE RIVER.

There are three projects adopted by the Government for the improvement of Santee River navigation. The Santee is formed by the junction of the Congaree and the Wateree rivers, 184 miles above the mouth of the Santee. The three projects united involve the improvement of the river up to Columbia on the Congaree and up to Camden on the Wateree, and provide for continuous 4-foot navigation throughout the entire distance. Up to June 30, 1905, $286,189 had been expended, while the approximate estimate for completion is $456,763.

Navigation on the main stream appears to be increasing. During the calendar year 1904 there were transported 242,800 tons, with a value of $1,652,000. There is every reason to believe that throughout the entire length of the main stream the transportation would be greater if a deeper channel could be provided and its maintenance assured. It will, therefore, be of interest to show how the depth during low-water seasons may be increased by conservation of flood waters in the basin of the Catawba River, which is the principal tributary of the Wateree. Inasmuch as the drainage area of the Congaree River lies outside of the proposed Southern Appalachian National Forest, no figures have been secured concerning its conservation possibilities. The effects of conservation at the headwaters of the Catawba River alone must be considered, but it should be remembered that in so doing we are taking into account only a part of the possibilities for improving navigation along the Santee.

Wateree.—In considering the added depth which will be gained by the proper use of these reservoirs it is necessary to consider the cross section of the Wateree River at Camden, where the United States Geological Survey has for many years maintained a gauging station and established a rating table. The relation of this section to sections below on the Santee are similar to those already discussed with reference to the Yadkin. The slope of the river at Camden is steeper than the general slope along the Santee, and although the Santee channel is of greater capacity the relation between this capacity and the rise of gauge height with increased flow is not proportional. It may be safely stated that the increase of 1 foot on the gauge at Camden, due to the influx of a certain quantity of water, will produce an equal, if not a greater, increase in the stage of the Santee River.

In the drainage area of the Wateree, 3 reservoir sites may be found of a capacity sufficient to store the entire annual flow from 720 square miles. Detailed facts concerning these sites are set forth in Table 7:

TABLE 7.—*Selected reservoir sites in the Wateree River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Catawba River, northwest Mecklenburg County, N. C.	420	1.64	700	24,970	420	77	18,250
Catawba River near Hickory, Catawba County, N. C.	600	1.64	980	9,870	190	100	7,760
Catawba River west of Morganton, N. C.	480	1.64	790	5,380	100	75	4,920

The ordinary low-water flow of Wateree River at Camden is about 3,000 second-feet. If the conserved area of 720 square miles be deducted from this, the low-water flow will be about 2,200 second-feet. The following table shows, in a manner similar to that for the rivers discussed in preceding pages, what may be accomplished at Camden by intelligent manipulation of reservoirs.

TABLE 8.—*Wateree River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	870	495	370	248
2	1,770	240	182	140
3	2,710	159	120	80
4	3,755	115	86	58
5	4,705	92	69	46
6	5,655	76	57	38

From Table 8 it may be seen that with a full reservoir capacity the stage of Wateree River at Camden can be increased 6 feet for a period of seventy-six days, or 3 feet for a period of one hundred and fifty-nine days. Considering the low-water period at an average of about four months, it will be seen that, reckoning on full reservoir capacity, the stage of Wateree River throughout such a period could be increased 4 feet by intelligent delivery from storage. The value of an added 4 feet to the stage of Wateree and Santee rivers and the guaranty of free and open navigation throughout the year can readily be appreciated by the people living in the valley of the Santee.

SAVANNAH RIVER.

The Savannah River is navigable from its mouth up to Petersburg, a distance of 48 miles above the city of Augusta. That part of the river above Augusta is not well adapted to open navigation because of its steep slope, while that part below Augusta has all the possibilities of a valuable highway. The river, as a whole, presents one of the best cases to demonstrate that the conservation of water and its proper manipulation may under certain conditions be far more effectual in maintaining navigable depths than any of the measures that have been included in the method of channel adjustment. Here is a river which, during the greater part of the year, is navigable for steamboats drawing from 4 to 5 feet of water, but which during low-water seasons is marked by shoals in its upper portion with low-water depth of not more than 3 feet. The improvement of this river, as outlined in the Report of the Chief of Engineers, U. S. Army, for 1890, is to be accomplished by removing sand and gravel bars, regulating portions of the river, revetting banks, and inclosing incipient cut-offs.

In pursuance of this plan the United States had expended up to June 30, 1905, the sum of $517,643, of which $58,935 was expended upon the river above Augusta. The estimate of the cost for completion of the present project is $645,045. The expenditures in the upper portion of the river have been suspended because the experience gained showed that a comprehensive plan for permanently improving this portion of the river would involve an expenditure of funds entirely out of proportion to the prospective commercial benefits. Therefore, navigation development in the Savannah River has been confined to that portion below the city of Augusta.

It is of interest to determine the effect of the proposed system of reservoirs on the navigation possibilities in the Savannah River. From topographic surveys already made 14 reservoir sites have been selected, the total capacity of which equals the run-off from 1,670 square miles of drainage area, which is equivalent to 23 per cent of the entire drainage area above Augusta. The facts concerning these reservoir sites are given in Table 9:

TABLE 9.—*Selected reservoir sites in the Savannah River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cu. ft.*	*Square miles.*	*Feet.*	*Acres.*
Keowee River, Pickens County, S. C.	270	3.45	930	25,130	230	150	11,240
Little River, Oconee County, S. C.	90	3.45	310	8,480	80	100	5,820
Twelvemile Creek, Pickens County, S. C.	160	3.45	550	2,210	20	50	3,030
Twenty-three Mile Creek, Anderson County, S. C.	150	3.45	520	15,370	140	70	6,620
Conneross Creek, Oconee County, S. C.	80	3.45	280	1,700	20	50	2,330
Tugaloo River, southwest Oconee County, S. C.	260	3.45	900	11,870	110	100	8,140
Chattooga River, west Oconee County, S. C.	120	3.45	410	9,470	90	150	3,310
Do.	190	3.45	660	15,920	140	150	4,690
Tallulah River, Rabun County, Ga.	130	4.35	570	2,440	20	90	1,860
South Fork River, Oglethorpe County, Ga.	260	1.89	490	1,940	30	50	2,600
Broad River, Madison County, Ga.	440	1.80	830	28,590	440	98	17,850
Hudson River, Banks County, Ga.	180	1.89	340	4,680	80	50	6,420
Beaver Dam Creek east of Elberton, Ga.	110	1.89	210	7,030	110	98	3,960
Rocky River, near Lowndesville, S. C.	240	1.89	450	9,680	160	100	6,580

Assuming that these reservoirs have been constructed and that they have been filled with flood waters which, in the present unrestrained state, do so great damage along the Savannah, what will be the effect in the cross section of the river at Augusta if the water is allowed to escape during the low-water season? The long series of records obtained by the United States Geological Survey at Augusta makes the determination of this point extremely simple. The results are embodied in Table 10, which shows the periods during which increased depth could be maintained at Augusta.

TABLE 10.—*Savannah River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	690	2,260	1,700	1,130
2	1,770	920	690	460
3	3,130	520	390	260
4	4,650	350	263	175
5	6,270	260	195	130
6	7,990	204	153	102
7	9,810	166	124	83
8	11,730	139	104	70
9	13,750	118	89	59

The facts indicated in Table 10 are the most remarkable yet presented. The amount of water that may be stored in these reservoirs is sufficient to maintain an added depth of 9 feet at the Augusta cross section for a period of one hundred and eighteen days, which is equivalent to an assumed low-water season of four months. Even if the reservoirs were only one-half full at the beginning of the low-water season there would still be an amount of water sufficient to add an additional 5 feet to the river for a period of one hundred and thirty days. The reservoir capacity set forth in Table 10 is probably greater than it would be necessary or economical to build. It is not the function of this paper to determine upon the proper capacity for development. On the contrary, the aim is to show only a part of the possibilities of water conservation. Neither in the case of the Savannah nor any other river discussed in this paper have the examinations been sufficiently extensive to give all the possibilities. Having discovered and verified a sufficient number for the purposes in view, the search has been discontinued. It should be remembered, also, that these possibilities are not confined in their application to the benefits to navigation, but extend to the prevention of floods, to the increase of water power and to all the other useful purposes to which water is put.

The Savannah River is an important stream commercially. During the year 1904 seven steamers were engaged in river traffic, making 300 round trips between Savannah and Augusta and carrying 61,353 tons of freight. There were also received at Savannah from this river in small boats and lighters 107,000 bushels of rice, valued at $82,600, and timber valued at $330,000. But the stretch between Savannah and Augusta would become a far more important artery of commerce than it is if a good navigable depth could at all times be assured.

ALTAMAHA RIVER.

Navigation on the Altamaha River and its tributaries covers 480 miles; 131 miles from the mouth to the junction of the Oconee and Ocmulgee rivers, 147 miles up the Oconee to Milledgeville, and 202 miles up the Ocmulgee to Macon. The Oconee at ordinary stages is navigable only to a point about 25 miles above Dublin, Ga., or a distance of 104 miles from the confluence, while the Ocmulgee during recent years has not been navigable, except at high water, above Hawkinsville, a distance of 133 miles from the confluence.

Navigation on the Altamaha consists largely of the rafting of lumber. During 1904 109,000,000 feet, valued at $1,350,000, passed down the river. The majority of this timber came from the Oconee and Ocmulgee rivers, though about 49,000,000 feet originated on the Altamaha. There were also 4,500 tons of freight, valued at $200,000.

The present project of the Government for the improvement of the Altamaha River provides for the establishment of a channel 3 feet deep at summer low water, to be accomplished by removing shoals and sand bars, building deflecting dikes, and inclosing incipient cut-offs. The amount expended on the work under the present project was, up to June 30, 1905, $74,362, of which $9,000 was for maintenance. This added to the amount previously expended gives a total of $144,139. The estimated cost of the completion of the project is $259,000.

Oconee.—On the Oconee River the present Government project provides for the establishment of a navigable channel 3 feet deep at ordinary summer low water from Milledgeville to the mouth, at a cost estimated at $171,000. The amount expended on this project to June 30, 1905, was $153,808. In 1904 the amount of freight was 32,160 tons, valued at $443,225. In addition to this, 60,000,000 feet of lumber were rafted down the stream. In spite of all expenditures the summer low-water depth is about 2½ feet between the forks and a point 25 miles above Dublin, and 1½ feet between this point and Milledgeville. The river occasionally falls below this stage and frequently rises to 20 feet above it.

Consideration will here be given only to the main stream and the Oconee, because the surveys made under the Appalachian National Forest project do not include the headwaters of the Ocmulgee, in which region there are many good reservoir sites which, if developed, would probably have as great beneficial effects on the main stream as those now to be discussed on the Oconee. Table 11 shows the reservoir sites which have been selected in the Oconee drainage basin.

TABLE 11.—*Selected reservoir sites in the Oconee River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Oconee River, Jackson County, Ga.	170	1.18	200	8,260	170	74	6,870
Middle and Mulberry Forks, Jackson County, Ga.	340	1.18	400	13,520	340	98	6,290

The two enormous reservoir sites set forth in Table 11 will conserve the mean annual discharge from 510 square miles of drainage area, and the total storage capacity will be 21,780,000,000 cubic feet. The Geological Survey has for many years maintained a station on the Oconee River at Dublin. The discharge of water from these reservoirs at different rates and under different conditions and the effects upon the river stage at that point are given in Table 12:

TABLE 12.—*Oconee River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	475	460	346	230
2	1,130	194	145	97
3	1,840	119	89	60
4	2,610	84	63	42
5	3,510	62	47	31

CHATTAHOOCHEE RIVER.

On the Chattahoochee River conditions are similar to those along other coastal streams which have been considered. The difficulties are lack of navigable depth at low-water seasons of the year, in spite of the expenditure of large sums of money by the Government. No increased depth has been gained, and each season has brought in greater quantities of sand, filling the original river bed and gradually changing its regimen. It is the endeavor to maintain a 4-foot draft at ordinary low water, but during some seasons a scant 3 feet can be carried. It is apparent, then, that the greatest need along the Chattahoochee is extra depth. Sufficient water can be stored in upland reservoirs to provide this. There are many good reservoir sites in the Chattahoochee basin; but of these, four are especially recommended. Their locations and characteristics appear in Table 13:

TABLE 13.—*Selected reservoir sites in the Chattahoochee River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Chattahoochee River north of Gainesville, Ga.	350	2.34	820	24,360	320	140	11,110
Chestatee River northwest of Gainesville, Ga.	140	2.34	330	10,640	140	100	7,300
Chestatee River east of Dahlonega, Ga.	150	2.34	350	3,300	40	100	2,260
Chattahoochee River east of White County, Ga.	110	2.34	260	5,520	70	100	3,790

The mean annual flow from 570 square miles can be entirely retained in these reservoirs. This amounts to 17 per cent of the entire drainage area above West Point. The effect of the discharge of water from these reservoirs during low-water seasons has been measured along the section of the river at West Point where a gauging station is maintained by the United States Geological Survey. It should be noted that the West Point station is in a steep portion of the stream and that the increase of stage here with a given quantity of water is not as great as it would be along the flat navigable part of the river below Columbus, Ga. Table 14 contains figures concerning the increase of stage at West Point:

TABLE 14.—*Chattahoochee River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	1,150	430	324	215
2	2,800	177	133	88
3	5,050	98	74	49
4	8,054	62	46	31

This completes the consideration of those Atlantic coast and Gulf rivers which collect a considerable part of their water within the area proposed as the Southern Appalachian National Forest. It will be seen that transportation on some of these rivers has been maintained in spite of the fact that at certain places navigable stages can not be guaranteed throughout the year. On other rivers traffic has waned because it has been found impossible or too expensive to maintain the proper navigable stage throughout the year. The regions traversed or drained by these rivers have, therefore, never had an opportunity to show how they might develop under an open system of navigation that could be depended on and that would encourage the construction and operation of modern steamboat lines.

RIVERS WHICH DRAIN INTO THE OHIO.

The problem of maintaining navigable depth in streams heading on the western slope of the Southern Appalachian Mountains is somewhat more complex than in those flowing from the eastern side. When the conserved water on the eastern side has fulfilled its purpose of maintaining navigation on the coastal streams during low-water seasons it passes into the Atlantic Ocean and is of no further use to inland shipping. When the stored water on the western slope has served the same purpose it passes into the Ohio River, thereby continuing its usefulness throughout the entire navigable length of that stream and even down into the Mississippi. It is necessary, therefore, not only to consider the various tributaries of the Ohio in the manner heretofore pursued, but their combined effect upon the main stem of the Ohio as well.

No treatment of water supply and navigation in the Ohio can be complete unless the Allegheny and the other northern tributaries are considered, but as their basins lie beyond the area of the proposed National Forest the scope of this paper must be confined to the southern tributaries.

MONONGAHELA RIVER.

The Monongahela River joins the Allegheny at Pittsburg to form the Ohio. Its channel is canalized from its mouth up to Fairmont, W. Va., the slack-water system comprising 15 dams and 19 locks. The 89 miles of channel in Pennsylvania was in its original condition prior to 1840 navigable for steamboats only at high stages, while that part in West Virginia was, in its original condition, impeded at high water by a swift current due to a fall of about 2 feet per mile. At low stages it was obstructed by shoals and numerous gravel and rock bars. Steamboat navigation was practicable at high stages as far upstream as Morgantown, W. Va.

The old Monongahela Navigation Company improved the river from Pittsburg to the West Virginia State line by building 7 locks and dams for slack-water navigation. The United States continued the improvement above the highest dam of this company and completed the project in November, 1889, with the result that boats drawing 5.2 feet of water could navigate in low stages as far upstream as Morgantown, W. Va. Further national improvement consisted of the construction of 6 more locks and dams, Nos. 10 to 15, inclusive, extending from Morgantown to Fairmont, W. Va. Subsequently the United States purchased the property of the Monongahela Navigation Company for $3,766,615, and the total cost for improvement of Monongahela River up to June 30, 1905, including this purchase money, was $6,023,605. For maintenance of these locks and dams up to June 30, 1905, the United States had paid $1,694,384, and the amount expended during the fiscal year ending at that date was $234,070.

From 1902 to 1905, inclusive, the tonnage carried on the Monongahela amounted to 9,500,000 annually, except in 1903, when the total was 11,369,814 tons, but during this period the passenger traffic steadily declined.

The Monongahela is formed a short distance above Fairmont by the junction of the Tygarts Valley River and the West Fork. The former stream drains an area of about 1,390 square miles of rugged country. The valley is valuable in mineral and timber products, but the excessive fall of the channel precludes the hope that it will be developed for navigation. West Fork, the other affluent, is comparatively sluggish and has practically the same slope as the Monongahela above the Pennsylvania line. Therefore it is readily adapted for navigation as far as Clarksburg, W. Va., with the depth which can be easily maintained at low water, either by the method of channel adjustment or by conservation. One-half the flow of the West Fork can be controlled, which would maintain the river at an almost constant stage throughout the year.

The Monongahela system of locks and dams was constructed, so far as public records show, without any suitable investigation of the possibilities of maintaining navigable stage in the river by conservation of flood waters. The idea that it might be possible to maintain navigable stage during low-water seasons by saving some of the water wasted during spring floods appears not to have been considered. The dams were constructed in the face of the knowledge that maintenance charges would be heavy and would continue generation after generation. The fact that they might be used for power development if sufficient summer flow were provided and so become self-supporting seems not to have made a strong impression. If this possibility had been taken into account it would not have been necessary to construct as many locks and dams as now exist along the river. The entire system up to Morgantown might have been abolished, as can be shown by information at hand.

There are in the Monongahela River basin eleven reservoir sites of a capacity sufficient to store the entire mean annual flow from 1,950 square miles. Detailed facts concerning these reservoirs are set forth in Table 15:

TABLE 15.—*Selected reservoir sites in the Monongahela River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Dunkard Creek, Monongahela County, W. Va.	160	1.7	270	8,300	150	100	5,800
Buffalo Creek, Mannington, W. Va.	40	1.7	70	2,400	40	59	2,100
Booths Creek, Monongah, W. Va.	40	1.7	70	2,800	40	101	1,600
Sandy Creek, Grafton, W. Va.	80	1.7	140	6,200	80	155	3,600
Teter Creek, Nestorville, W. Va.	40	1.7	60	2,600	40	115	1,300
Elk Creek, Clarksburg, W. Va.	100	1.7	170	5,900	100	92	4,800
West Fork River, Clarksburg, W. Va.	380	1.7	640	24,700	380	109	15,900
Buckhannon River, Buckhannon, W. Va.	310	1.7	530	18,800	310	77	13,300
Middle Fork Tygart, Barbour County, W. Va.	140	1.7	230	8,100	140	107	4,300
Cheat River, Tucker County, W. Va.	820	1.7	1,400	23,800	440	200	6,000
Tygart River, Beverly, W. Va.	330	1.7	560	19,100	330	142	10,000

With the above reservoirs in operation, the entire flow from 2,050 square miles, or 35 per cent of the drainage area of the Monongahela above the mouth of the Youghiogheny, can be cut out of the drainage system for a year, or, in other words, they can retain an entire year's flow from that area until such a time as the conditions on the lower river make it necessary to use the water for purposes of navigation. In order to show what additional depth might be maintained on the Monongahela, three sections have been sounded, measured and rated, so that the effect of discharge on the stage of water may be accurately determined. These sections are as follows: First, about one-half mile below the bridge at Morgantown, W. Va.; second, at Brownsville, Pa.; third, below McKeesport, Pa. These sections were chosen so as to cover the extreme and average ranges of slope in the canalized portion of the river below Morgantown.

Table 16, similar to those already presented, shows what may be accomplished in the Monongahela by proper manipulation of storage reservoirs.

TABLE 16.—*Monongahela River.*

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
SECTION BELOW MORGANTOWN BRIDGE.				
1	545	1,650	1,240	825
2	1,290	760	525	350
3	2,300	392	293	196
4	3,600	250	188	125
5	5,030	179	134	90
6	6,760	133	100	66
SECTION AT BROWNSVILLE, PA.				
1	780	1,740	1,300	870
2	1,700	730	550	365
3	3,070	410	310	205
4	4,670	270	203	135
5	6,570	193	145	96
6	8,730	139	104	70
SECTION BELOW McKEESPORT, PA.				
1	1,080	1,500	1,120	750
2	2,470	650	490	325
3	3,940	410	310	205
4	5,840	280	210	140
5	8,000	200	150	100
6	10,340	156	117	78

Table 16 may be interpreted thus: A stage of water in the Monongahela 6 feet additional to that caused by the normal dry season flow may be maintained throughout the longest dry season ever known in the history of the river. The money used for slack-water navigation might better have been spent in the hills, but now that the dams are erected the proper course is to reserve the Monongahela highlands and to produce profitable power on these dams so that the system will be self-supporting.

Youghiogheny.—The Youghiogheny is the most important tributary of the Monongahela. Its drainage basin lies within the State of Pennsylvania and comprises 1,750 square miles. It joins the Monongahela at McKeesport, 15 miles above the Ohio.

Navigation on the Youghiogheny has given considerable trouble in the past. About 1850 a company was chartered by the State of Pennsylvania to build 2 locks and dams to carry the slack water 12 miles to Alpsville. The lock had lifts of from 12 to 15 feet, but the structures were not well built, traffic was small, and they were finally destroyed by floods and ice. The report of the Chief of Engineers, U. S. Army, for 1900 recommends the extension of the slack-water navigation as far up as Connellsville. The proposition involves the construction of locks and dams at the head of Little Falls, at the head of Middleshoot, and at the rapids above Great Falls. The total cost of these 3 locks and dams was estimated at about $600,000.

Along the entire length of the Youghiogheny, from its mouth to Connellsville, there are heavy deposits of bituminous coal, and Connellsville is the center of the coke and iron district. The Ohio River affords a convenient outlet for these products. The prospective annual river tonnage, exclusive of coal, is estimated to amount to something like 75,000 tons, and it is further estimated that a Youghiogheny slack-water system would take not less than 40 per cent of the coal lying near the river away from the railroads. The output in 1898 was 1,576,097 tons.

The great difficulty in the way of the development of the Youghiogheny arises from the steep slope of the channel, and, more important, the exceedingly small supply of water during summer and fall. In 1904 the minimum run-off of the Youghiogheny at Connellsville was only about 59 cubic feet per second. Out of the 93 days during the last three months of the year the river discharged less than 150 cubic feet per second for 87 days.

Table 17 gives facts concerning selected reservoirs in the Youghiogheny basin. The area covered does not include the tributary basins of Laurel and Castleman's rivers, which comprise 32 per cent of the entire Youghiogheny drainage area. Rapid reconnaissance of these tributaries shows them to be at least as well supplied with reservoir sites as the Upper Youghiogheny itself.

TABLE 17.—*Selected reservoir sites in the Youghiogheny River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Youghiogheny River, Friendsville, Md	270	2.47	690	20,270	255	240	4,220
Deep Creek, Garrett County, Md	55	2.47	136	4,603	55	83	3,200
Cherry Creek, Garrett County, Md	55	2.47	136	4,912	55	64	3,980
Muddy Creek, Garrett County, Md	13	2.47	32	1,065	13	70	1,100
Herrington Creek, Garrett County, Md	13	2.47	32	900	11	60	700

Table 17 shows that the storage capacity is not sufficient to provide a navigable stage in Youghiogheny River during the low-water season, and it is doubtful whether if the additional storage on the unsurveyed portions of the basin were taken into account there would be a sufficient supply for this purpose. The course of the river below Connellsville is fairly steep, and here is presented one of the cases in which canalization is apparently the only solution. In connection with the plans for such work, it will be well to consider the possibility of making this slack-water system pay for itself by utilizing the excellent power possibilities that will be made available at the dams. The part of the river that it is proposed to canalize is in the midst of a great center of industry, and the power derived would find a ready market at prices that would make the investment remunerative. There is presented here a condition identical with that on the Monongahela before canalization, but here there is the added advantage that the proposed Youghiogheny system is a new one and no mistake need be made. The way to utilize the available power along this stream is to develop coincidently with canalization the conservation system outlined in Table 17 and to provide that the upland area shall be set apart as a reserve, so that the natural conditions of forestation will not be destroyed.

The dams constructed for slack-water navigation, according to the plans that have been approved by the Chief of Engineers, U. S. Army, will afford a total fall of 30 feet. The minimum flow for the six highest months along this portion of the Youghiogheny is about 1,000 cubic feet per second, while the water from the above-mentioned reservoirs if distributed over twelve months would be about 950 cubic feet per second. Considering only the minimum flow for the six highest months and the proper manipulation of the water in storage, there would be insured a discharge of at least 1,500 cubic feet per second throughout the year at the various dams proposed under the slack-water system. This amount of water, allowing for necessary loss by leakage and lockage, would insure the production of 4,100 horsepower, which would at times be greatly exceeded. Figuring on an average rental of $20 per horsepower per year (it would be considerably greater in this situation), the total income would be $82,000, which represents an interest of 3 per cent on about $2,700,000.

This provides a specific illustration of the policy that should prevail in connection with improvements for inland navigation. Under it water and power now wasted would be put to productive use and the cost of the canalization and conservation would be returned, in marked contrast to the present policy, which involves a constant drain on the National Treasury.

KANAWHA RIVER.

The project for improvement of navigation on Kanawha River, adopted in 1875, provided for maintaining a depth of 6 feet throughout the year over a distance of 96 miles from its confluence with the Ohio. For 79 miles, or from the confluence up to Paint Creek, this was accomplished by 8 movable dams and for the remainder of the distance by 2 fixed dams. These dams have been completed and are now in operation. Up to June 30, 1905, the United States had expended $4,124,526 for improvement and $656,986 for care and operation, the latter expense increasing annually. The commerce on the river for the calendar year 1905 amounted to 1,613,899 tons, with a valuation of $6,865,521, against 1,233,153 tons, with a valuation of $7,899,000, for the year 1904.

It is proposed to show what the effect would have been on the original bed of Kanawha River, before the introduction of the present canalization system, had the possibilities for conservation been utilized, and to show that the great expenditures for canalization might have been avoided and a large part, at any rate, of the money so expended used for the construction of reservoirs in the mountains. The problem is similar to that just considered on the Monongahela.

Topographic survey of the Kanawha drainage area reveals 17 reservoir sites having a storage capacity of 280,750,000,000 cubic feet, sufficient to retain the annual run-off from 5,180 square miles in the drainage area, or about 43 per cent of the entire basin. Detailed facts concerning these reservoir sites are set forth in Table 18:

TABLE 18.—*Selected reservoir sites in the Kanawha River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cubic ft. per sec.*	*Cubic ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Greenbrier River, Pocahontas County, W. Va.	320	1.44	460	16,300	320	177	4,700
Elk River, Clay County, W. Va.	940	1.44	1,350	49,900	940	190	15,700
Greenbrier River, Lewisburg, W. Va.	680	1.44	980	32,900	680	164	11,600
Meadow River, Greenbrier County, W. Va.	180	1.44	250	8,000	180	80	7,000
Muddlety Creek, Nicholas County, W. Va.	60	1.44	90	3,400	60	74	2,600
Blue Creek, Kanawha County, W. Va.	60	1.44	90	3,300	60	97	2,300
Gauley River, Fayette County, W. Va.	1,290	1.44	1,860	35,900	780	250	7.500
New River, above mouth Greenbrier River	3,600	1.6	5,750	20.300	390	135	8.000
Walker Creek, Giles County, Va.	310	2.02	620	6,550	190	110	3,000
New River, Radford, Va.	1,740	2.02	3,500	59.400	920	125	23,000
Reed Creek, Wythe County, Va.	250	2.02	510	6,400	160	160	4,500
Big Reed Island Creek, Pulaski County, Va.	380	2.02	770	4,000	60	100	2,900
Cripple Creek, Wythe County, Va.	180	2.02	370	2,900	40	100	2.000
New River, Carrol County, Va.	1,290	2.02	2,600	19,400	800	200	6,200
Eighteen-Mile Creek, Putnam County, W. Va.	60	1.3	80	4,000	60	68	2,300
Thirteen-Mile Creek, Mason County, W. Va.	80	1.3	100	3,400	80	61	2,000
Pocotaligo River, Putnam County, W. Va.	230	1.3	300	4,700	110	65	3,900

For the purpose of determining the effect of this storage upon the stage of Kanawha River, two sections have been surveyed and rated so that the effect of increased discharge on gauge heights in the channel can be accurately determined. These sections are located one above Lock No. 6, where the natural slope was fairly steep for this part of the river, and one below the mouth of Elk River, where the slope was very slight. The effects of discharge from storage at various rates upon the stages of these two sections are set forth in Table 19:

TABLE 19.—*Kanawha River.*

SECTION ABOVE LOCK No. 6.

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cubic feet per sec.*	*Days.*	*Days.*	*Days.*
1	1,570	1,860	1,400	930
2	3,420	850	640	425
3	5,680	514	380	257
4	8,400	347	260	174
5	11,400	256	192	128
6	14,800	197	148	98
7	18,300	160	120	80

SECTION BELOW ELK RIVER.

(About 2½ miles above Lock No. 6.)

1	700	4,170	3,100	2,085
2	1,630	1,790	1,340	895
3	2,650	1,100	830	550
4	3,710	790	590	395
5	5,000	580	440	290
6	6,400	460	340	230
7	8,000	365	270	182

From Table 19 it is seen that the storage proposed on the upper drainage area is sufficient to prolong at the steeper section an additional 7-foot stage for a period of one hundred and sixty days with reservoirs full, or one hundred and twenty days with reservoirs three-fourths full, while at the flat section below the mouth of Elk River the effect is far more marked and the additional discharge of 8,000 cubic feet per second raises the stage 7 feet. The possibilities along this portion of the river for the maintenance of stage by stored waters are so great that it is evident that the installation of the expensive lock and dam system was unnecessary throughout that portion, at least, in which the movable dams have been installed.

It is necessary to omit from this paper consideration of the effects of the proposed National Forest on navigation in the Big Sandy, Kentucky, and Cumberland rivers. The greater part of the headwaters of the Big Sandy and smaller portions of the headwaters of the other two streams are included within the proposed area and therefore their effects upon navigation are a legitimate consideration in this paper, but, unfortunately, the surveys available and the records of stream flow are not sufficiently complete to serve as a basis.

TENNESSEE RIVER.

The Tennessee River forms a system of internal waterways navigable by steamboats for more than 1,300 miles. The main river, formed by the junction of the French Broad and Holston rivers, 4½ miles above Knoxville, Tenn., is 652 miles long. Throughout the year the river is navigable from the mouth to Riverton, Ala. Just above Riverton, at Colbert and Bee Tree shoals, a lateral canal 8 miles long is under construction. Another canal 3 miles long is projected at Little Muscle Shoals, just above Florence, Ala., and the Muscle Shoals canal crosses the Big Muscle and Elk River shoals. There is now no through traffic covering the entire year. The longest regular boat service is that between Chattanooga and Paducah.

In the year 1904 the tonnage amounted to 1,607,000, valued at $30,000,000. The amount allotted for Tennessee River improvements and canals up to June 30, 1905, was $7,170,000. Of this sum $913,419 was spent for operation, care, and repair of Muscle Shoals Canal from November 30, 1890, to June 30, 1905.

The improvement of the river has been carried on in three sections—first, that part of the river above Chattanooga, Tenn.; second, that lying between Chattanooga and Riverton, Ala., and, third, that from Riverton to the mouth. The character of these improvements is as follows:

First section: above Chattanooga.—The attempt here is to obtain by training walls, wing dams, and dredging a low-water channel of 3 feet from Chattanooga to the mouth of French Broad River, at an estimated cost of $650,000. The maximum draft that can be carried at mean low water over the shallowest places in this section is about 18 inches, and the extreme flood oscillations range from 40 feet at Knoxville to 58 feet at Chattanooga. The very small depth at mean low water and the enormous range of stage in the river are quite suggestive of what might be accomplished in the maintenance of a high navigable stage if a part of the flood waters could be held back and distributed through the low-water season. It has been demonstrated that the desired 3-foot stage will not encourage any great amount of water transportation along this section of the river, because, as has been said in this paper, transportation conditions are such that small-draft boats can not be operated with profit. A later paragraph will show what may be accomplished by means of storage reservoirs.

Second section: between Chattanooga and Riverton.—This section was originally obstructed between Chattanooga and Browns Ferry by bars, bowlders, and reefs. Navigation is possible on this section from six to nine months annually. Between Florence and Riverton, Colbert and Bee Tree Shoals prevent navigation six months in the year, but, as explained in a preceding paragraph, this obstruction is to be overcome by canalization. The present project provides for a lock and dam to be built, mainly by private parties, 33 miles below Chattanooga, forming a pool that will extend to that city with a depth of at least 6 feet at low water, together with the construction of a lateral canal about 8 miles long with one lock. The total amount spent on this section of the river, from Chattanooga to Riverton, up to June 30, 1905, was $1,550,000. Although there is greater need for canalization along the second than along the first section because of the existence of abrupt falls, there are long stretches of the river in which the slope is very gradual and in which the conditions for improvement by the release of conserved waters during the low-water season are ideal. The effect of such discharge will be noted in a later paragraph.

Third section: from Riverton to Paducah.—This part of the river has a moderate and uniform slope with original low-water depth of about 3.5 feet over its lower 196 miles and 2 feet over the remainder of the distance to Riverton. The present project is to obtain, by dredging, a channel not less than 5 feet deep. The total amount expended to June 30, 1905, was $279,663. The extreme flood oscillations at Jacksonville are 48 feet and at Paducah 55 feet. The commerce along the river between Florence and Paducah during the year 1904 amounted to 871,380 tons.

It will be noted that this flat section of the river, which is subject to such great oscillations by reason of flood discharge, is entirely subject to convenient regulation if the necessary water can be provided from storage. It will also be noted that the 5-foot channel is to be secured and maintained by dredging, which means continual work and large maintenance expenses for the purpose of removing the silt and gravel that will be deposited in the channel each season. The defects are subject to correction by the maintenance of uniform flow of sufficient amount to secure a desired stage. Such an amount of water would also produce a uniform deposition of gravel, and eventually a proper slope and capacity for the discharge would be effected, so that a permanent channel could always be depended upon.

The storage possibilities in the upper part of this basin which it is proposed to include in the National Forest are set forth in Table 20. It will be noted that the total storage is considerably greater than will be necessary to effect the improvement advocated; but as the purpose of this paper is to show possibilities rather than to present finished plans for improvement, no estimate has been made of the precise storage desired or needed.

TABLE 20.—*Selected reservoir sites in the Tennessee River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Clinch River, Scott County, Va.	780	1.38	1,080	30,400	600	180	10,600
Nolichucky River, Greenville, Tenn.	940	1.69	1,590	14,700	270	100	10,200
Clinch River, Sneedville, Tenn.	560	1.38	770	18,500	300	100	8,500
Powell River, Jonesville, Va.	570	1.38	790	17,100	380	100	12,000
Holston River, northeast of Knoxville, Tenn.	3,400	1.56	5,300	163,500	3,300	160	49,000
French Broad River, east of Knoxville, Tenn.	4,050	1.56	6,300	199,600	4,000	200	70,000
Little River, south of Knoxville, Tenn.	290	1.56	450	17,400	290	94	12,100
Little Tennessee River, Loudon County, Tenn.	2,520	2.78	7,000	78,000	880	100	54,400
Little Tennessee River, Swain County, Tenn.	380	2.78	1,050	7,340	80	100	5,120
Clinch River, Roane County, Tenn.	2,110	1.38	2,900	26,500	600	60	30,000
Cheoah River, Graham County, N. C.	180	2.78	500	6,700	75	150	2,840
Hiwassee River, Cherokee County, N. C.	550	2.63	1,450	32,200	380	200	11,000
Nottely River, Union County, Ga.	240	1.70	410	1,000	20	40	1,600
Toccoa River, Fannin County, Ga.	240	2.14	510	4,130	60	160	2,800
Hiwassee River, Hiwassee, Ga.	100	2.63	260	2,240	40	100	1,600
Tennessee River, Rabun, Ga.	50	4.35	220	2,720	20	50	3,800
Hiwassee River, near mouth, Tenn.	2,040	2.12	4,300	77,500	1,130	70	70,000
West Chickamauga Creek, Walker County, Ga.	80	2.00	160	5,200	80	60	6,200
South Chickamauga Creek, Catoosa County, Ga.	110	2.00	220	6,330	100	60	7,400
Sequatchie River, Sequatchie County, Tenn.	330	2.00	660	4,000	60	50	5,500

Table 21 shows the effect of the regulated discharge of the stored water along three sections of the river; the first at Knoxville, the second at Chattanooga, and the third below Riverton. The facts given apply to the three sections of the river along which improvement has been attempted, and, although the total storage indicated in Table 20 is not necessary for purposes of navigation, the effects of that storage in increasing the stage of the river during low-water seasons are given in Table 21:

TABLE 21.—*Tennessee River.*

SECTION AT KNOXVILLE.

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cu. ft. per sec.*	*Days.*	*Days.*	*Days.*
1	970	4,250	3,187	2,125
2	3,220	1,280	960	640
3	6,380	647	485	323
4	9,930	416	312	208
5	13,700	300	225	150
6	17,670	233	174	116
7	21,840	189	142	95
8	26,210	157	117	78
9	30,780	134	100	67
10	35,300	117	87	58

TABLE 21.—*Tennessee River*—Continued.

SECTION AT CHATTANOOGA.

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cu. ft. per sec.*	*Days.*	*Days.*	*Days.*
1	2,780	2,890	2,167	1,445
2	6,540	1,230	922	615
3.	11,040	728	546	364
4	16,000	502	376	251
5	25,560	314	235	157
6	27,870	288	216	144
7	34,470	233	174	116
8	41,070	196	147	98
9	47,670	168	126	84
10	54,270	148	111	74

SECTION BELOW RIVERTON.

1	1,440	5,600	4,200	2,800
2	4,200	1,900	1,430	950
3	7,600	1,060	790	530
4	11,500	700	520	350
5	15,900	500	380	250
6	20,800	390	290	195
7	26,000	310	230	155
8	31,600	250	190	125
9.	37,500	210	160	105
10	43,600	180	138	90

OHIO RIVER.

This brings the discussion to a point where the consideration of the effects of storage reservoirs upon navigation in the Ohio itself can be taken up. To show fully what the effect would be it would be necessary to have complete figures of storage capacity on all the upland drainage areas contributing to the Ohio. Such complete data are not at hand, and it will be necessary, therefore, to confine statements to the effect of the three streams that have been discussed, namely, the Monongahela, the Kanawha, and the Tennessee. This will by no means do justice to the situation. Whatever is shown to be the effect on the Ohio of discharge from the reservoirs on these upland rivers, it should be remembered that such effect is far less than that which would take place were all contributory basins included in the estimate.

A complete treatment of the subject would involve an investigation of the effect of the reservoirs mentioned on numerous sections of the Ohio, from the mouth of the Monongahela to Cairo, Ill., but in the limited space of this paper it will be possible to consider only three representative sections, at Wheeling, W. Va., Huntington, W. Va., and Paducah, Ky.

The following is a résumé of the attempts that have been made to render the river navigable during low-water seasons in the project under which the Government is now working for the improvement of the Ohio.

Work was commenced by the Federal Government on the Ohio River in 1827; it has embraced the removal of obstructions, the construction, repair, and maintenance of low concentrating dikes and dams, bank protection, and the building and repair of levees. The Government had expended up to June 30, 1905, the sum of $6,696,000. Commerce on the river during the calendar year 1905, so far as reported, was approximately 13,000,000 tons, valued at $22,000,000, together with more than 4,000,000 passengers.

Permanent improvements so far made on the Ohio River consist of the construction of several locks and dams, which are intended to be the first of a series which will constitute a general system of canalization. In the river and harbor act approved March 3, 1905, is a provision for the appointment of a board of engineers "to examine the Ohio River and report at the earliest date by which a thorough examination can be made, the necessary data with reference to the canalization of the river, and the approximate location and number of locks and dams in such river, with a view both to a depth of 6 and 9 feet; and to include the probable cost of such improvement with each of the depths named, the probable cost of maintenance and the present prospective commerce on said river," etc. The report of this board of engineers had not been made at the time of the issuance of the last annual report of the Chief of Engineers, but the intent of the act is plain, viz, to determine upon a scheme of canalization in pursuance of the plan already started. A great many locks and dams will be needed to complete the canalization of the river, for the Ohio at times flows so low that navigation throughout the greater part of the stretch is entirely suspended. In view of the approach of this report it is extremely pertinent to consider what may be done by the use of conservation reservoirs.

For the three sections mentioned rating tables have been made showing the effect of increased discharge on the height of the river at these sections. The Ohio section at Wheeling shows the effect of the discharge of stored water on the Monongahela River alone, that at Huntington the combined effect of the Monongahela and Kanawha, while that at Paducah presents the effect of the Monongahela, Kanawha, and Tennessee. Table 22 embodies this information.

TABLE 22.—*Ohio River.*

SECTION AT WHEELING.

Increase of stage.	Flow required.	Duration of flow.		
		Reservoirs full.	Reservoirs three-fourths full.	Reservoirs one-half full.
Feet.	*Cu. ft. per sec.*	*Days.*	*Days.*	*Days.*
1	3,000	540	405	270
2	6,700	240	180	120
3	11,610	139	105	70
4	18,020	90	67	45
5	25,300	64	48	32
6	32,800	49	37	25
SECTION AT HUNTINGTON.				
1	8,100	580	430	290
2	17,600	267	200	133
3	28,600	164	123	82
4	39,600	118	89	59
5	51,600	91	68	46
6	63,600	74	55	37
7	77,000	60	45	30
SECTION AT PADUCAH.				
1	11,000	1,160	870	580
2	24,000	530	400	265
3	39,000	330	245	165
4	55,000	232	174	116
5	68,000	187	140	94
6	83,000	153	115	76
7	98,000	94	71	47

Table 22 shows that available storage facilities in the Monongahela basin alone will serve to increase the stage at Wheeling 3 feet for considerably more than four months, while the combined effect of the Monongahela and Kanawha at Huntington will afford an increase of 4 feet above the low stage for four months. In the third part of the table the effect of stored water from the Tennessee is appreciable, and it is seen that for a period of one hundred and fifty-three days, or five months, an additional stage of 6 feet could be maintained in this section.

CONCLUSION.

In conclusion, the figures given in this report bear out the statement made at the beginning that the proper improvement of many rivers may be practically and thoroughly accomplished only by the use of storage reservoirs and the retention of the forest cover. On some of the rivers the possibilities are greater than on others and on some, like the Yadkin, the possibility of maintaining high navigable stages during low-water seasons is considerably greater than is shown in the table. No rated section was available in the lower or navigable portion of the Yadkin and it was necessary to make the estimate on a section of high slope in which the increase of stage due to increment of stored water is not as great as it would be below. Moreover, on several of the streams, because of lack of survey, only a part of the upland drainage areas was considered and the results given are based only on the storage discovered along the surveyed portions. The effects are in no case overestimated; on the other hand, with many of the rivers the possibilities are far greater than are shown in the tables.

The second important point brought out in this report is that conservation of stream flow depends upon the condition of the drainage area, and that to insure the perpetuation of the proper conditions it is necessary to preserve the forests and keep the land surfaces intact. If this is done by such reservation, many values will be affected. The conservation of flood waters and the increase of water power are among the most important, but in the consideration of the cost of this reserve it should be borne in mind that, disregarding all other improvements, the benefit accruing to navigation alone would more than justify the necessary expenditure. Therefore, the preservation of timber resources, of water power, the prevention of flood damages, may, if need be, be considered as collateral benefits, though these benefits equal in importance the benefit to navigation.

Approved:
JAMES WILSON,
Secretary of Agriculture.
WASHINGTON, D. C., *January 15, 1908.*

O

Walter Mulford

Issued March 20, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—Circular 144.

GIFFORD PINCHOT, Forester.

(IN COOPERATION WITH THE DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY, GEORGE OTIS SMITH, DIRECTOR.)

THE RELATION OF THE SOUTHERN APPALACHIAN MOUNTAINS TO THE DEVELOPMENT OF WATER POWER.

By

M. O. LEIGHTON, M. R. HALL, AND R. H. BOLSTER,

U. S. GEOLOGICAL SURVEY.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1908

On March 4, 1907, Congress passed the following provision in connection with the Agricultural appropriation bill:

> *Survey of and report on Appalachian and White Mountain watersheds.*—To enable the Secretary of Agriculture to examine, survey, and ascertain the natural conditions of the watersheds at and near the sources of the various rivers having their sources in the Southern Appalachian Mountains and the White Mountains, and to report to Congress the area and natural conditions of said watersheds, the price at which the same can be purchased by the Government, and the advisability of the Government purchasing and setting apart the same as national forest reserves for the purpose of conserving and regulating the water supply and flow of said streams in the interest of agriculture, water power, and navigation. * * *

Because of its identification with studies of stream flow and its facilities for stream measurement, arrangement was made with the Geological Survey for a study of the water resources of the Southern Appalachian Mountains. The following report on The Relation of the Southern Appalachian Mountains to the Development of Water Power has resulted from that study.

CONTENTS

Page.
Introduction........ 7
Rivers on Atlantic Seaboard........ 10
    Potomac River........ 10
        North Branch........ 11
        South Branch........ 12
        Shenandoah River........ 12
    James River........ 14
        Tributaries........ 15
    Roanoke River........ 16
        Tributaries........ 17
    Pedee River (Yadkin)........ 18
        Tributaries........ 19
    Santee River........ 20
        Catawba River........ 20
        Congaree River........ 22
            Broad River........ 22
                Tributaries of Broad River........ 23
            Saluda River........ 23
    Savannah River........ 24
        Tugaloo River........ 25
            Chattooga River........ 25
                Tributaries of Chattooga River........ 26
            Tallulah River........ 26
        Seneca River........ 27
    Chattahoochee River........ 28
        Tributaries........ 29
    Coosa River........ 29
        Etowah River........ 31
Ohio River Tributaries........ 32
    Monongahela River........ 32
        Tygarts Valley River........ 34
        West Fork........ 34
        Other Tributaries of Monongahela River........ 35
            Cheat River........ 35
            Buckhannon River........ 35
            Middle Fork........ 35
            Youghiogheny River........ 36
    Great Kanawha River........ 37
        Tributaries of Great Kanawha River........ 38
            South Fork of New River........ 38
            North Fork of New River........ 38
            Greenbrier River........ 39

Ohio River Tributaries—Continued.
Great Kanawha River—Continued.
Tributaries of Great Kanawha River—Continued.

Page.
Gauley River 39
Tributaries of Gauley River 40
Elk River 41
Tributaries of Elk River 41
Tennessee River 41
Hiwassee River 43
Tributaries of Hiwassee River 44
Clinch River 45
Tributaries of Clinch River 45
Little Tennessee River 46
Tributaries of Little Tennessee River 47
Tellico River 47
Citico Creek 47
Abrams Creek 47
Cheoah Creek 47
Tuckaseegee River 48
Nantahala River 48
French Broad River 49
Tributaries of the French Broad River 49
Little Pigeon River 49
Nolichucky River 50
Pigeon River 50
Holston River 52
South Fork 52
Tributaries of South Fork 53
North Fork 53
Conclusion 54

TABLES.

Page.

TABLE 1. Rivers investigated 9

2. Selected reservoir sites in the Potomac River basin 10

3. Indicated horsepower developed by Potomac River between tide water and Harpers Ferry 10

4. Indicated horsepower developed by Potomac River between Harpers Ferry and the junction of North and South branches 11

5. Indicated horsepower developed by South Branch of Potomac River. 12

6. Indicated horsepower developed by Shenandoah River 13

7. Selected reservoir sites in the James River basin 14

8. Indicated horsepower developed by James River between Richmond and Eagle Mountain and by Jackson River between Clifton Forge and Back Creek 15

9. Selected reservoir sites in the Roanoke River basin 16

10. Indicated horsepower developed by Roanoke River between Weldon, N. C., and junction of North and South forks 17

11. Selected reservoir sites in the Yadkin River basin 18

12. Indicated horsepower developed by Yadkin River between the mouth of Uharie River and Buffalo Creek 19

13. Indicated horsepower developed by tributaries of Yadkin River (except South Yadkin and Ararat rivers) 20

14. Selected reservoir sites in the Catawba River basin 20

15. Indicated horsepower developed by Catawba River between the mouth of Wateree Creek and the mouth of North Fork 21

16. Indicated horsepower developed by Congaree and Broad rivers.. 22

17. Indicated horsepower developed by Saluda River and principal tributaries 23

18. Selected reservoir sites in the Savannah River basin 24

19. Indicated horsepower developed by Savannah River between Augusta, Ga., and Seneca River 25

20. Indicated horsepower developed by Chattooga River between its confluence with the Tallulah and West Fork 26

21. Indicated horsepower developed by Tallulah River 27

22. Selected reservoir sites in the Chattahoochee River basin 28

23. Indicated horsepower developed by Chattahoochee River between Columbus and Santee Creek 29

24. Selected reservoir sites in the Alabama River basin 30

25. Indicated horsepower developed by Coosa River between Wetumpka and Rome 30

26. Indicated horsepower developed by Etowah River 32

27. Selected reservoir sites in the Monongahela River basin 33

28. Indicated horsepower developed by Monongahela River 33

29. Indicated horsepower developed by Tygarts Valley River 34

30. Indicated horsepower developed by Cheat River 35

Page.
TABLE 31. Selected reservoir sites in the Youghiogheny River basin.......... 36
32. Indicated horsepower developed by Youghiogheny River between McKeesport and the source.......... 36
33. Indicated horsepower developed by Great Kanawha River between Pool No. 2 and confluence of North and South forks.......... 38
34. Indicated horsepower developed by Greenbrier River.......... 39
35. Indicated horsepower developed by Gauley River.......... 40
36. Indicated horsepower developed by tributaries of Gauley River.... 40
37. Indicated horsepower developed by Elk River.......... 41
38. Selected reservoir sites in the Tennessee River basin.......... 42
39. Indicated horsepower developed by Hiwassee River.......... 43
40. Indicated horsepower developed by Ocoee-Toccoa River.......... 44
41. Indicated horsepower developed by Clinch River.......... 45
42. Indicated horsepower developed by Powell River and tributaries.. 46
43. Indicated horsepower developed by Little Tennessee River.......... 47
44. Indicated horsepower developed by Tuckaseegee River.......... 48
45 Indicated horsepower developed by French Broad River.......... 49
46. Indicated horsepower developed by Nolichucky River and tributaries.......... 50
47. Indicated horsepower developed by Pigeon River and tributaries.. 51
48. Indicated horsepower developed on other important tributaries of French Broad River.......... 52
49. Indicated horsepower developed by South Fork of Holston River.. 52
50. Indicated horsepower developed by Watauga River and tributaries.. 53

THE RELATION OF THE SOUTHERN APPALACHIAN MOUNTAINS TO THE DEVELOPMENT OF WATER POWER.

INTRODUCTION.

Water power is a prime factor in the present industrial development of the South. The abundance of water supply and the slope of rivers have recently brought to the region watered by streams from the Southern Appalachian Mountains the greatest development of water power that has ever taken place, during a similar period, anywhere in the United States. The resource represented by this water power is far greater than its present market value. Fuel must become more and more costly as the available supply is depleted. This means that the cost of fuel power, which is at present much greater than that of water power, will constantly increase, and the demand for water power will increase in proportion. A low average of the present rental value of water power is $20 per horsepower per year. This figure will be used in this report to estimate the present value of the power available for development in the Southern Appalachian region. The future value can not be estimated.

According to estimates made by the United States Geological Survey there is a minimum of about 2,800,000 indicated horsepower developed by the rivers having their headwaters in the Southern Appalachian Mountains. Mature consideration of the condition leads the Survey to estimate that at least 50 per cent and probably much more of this indicated power is available for economic development. It should be borne in mind that this figure represents merely the mimimum horsepower. If auxiliary power were provided to supply short seasons of water deficiency it would be profitable to develop up to 2½ times this amount. Full development of storage facilities would increase the minimum from 3 to 30 times. Obviously an estimate of present value based on 50 per cent of the minimum indicated horsepower is sure to be extremely conservative.

The rental of 1,400,000 horsepower at $20 per horsepower per year would amount to an annual return of $28,000,000. This amount is equal to a gross income of 3 per cent on a capital of about $933,000,000. Some of this power has already been developed, but a very small proportion—hardly enough to make any appreciable showing when the enormous resources of the region are taken into account.

The above estimates of power are based on present condition of the drainage areas. They represent what can be accomplished if the present forests of the mountains are protected from this time on.

Abuse of many of the important upland areas has already largely reduced the availability of the power which is present, and the further such abuse extends the less available the power will be.

The amount of power that can profitably be developed on any stream is governed by the length and severity of the low-water season—not by the height and violence of the floods. The more uniform the flow of a river, the more valuable it becomes for power as well as for all other purposes, and uniformity of flow is dependent chiefly upon the condition of the land surface. Rain which falls upon an asphalt-paved street drains away sooner than that which falls upon a country lane. The same principle holds for all land surfaces. An upland denuded of forests and with land surface hardened and baked by exposure discharges the rain water into the streams and rivers in great floods, and retains no water to supply the rivers in the dry season. In discharging in this torrential way, the water carries along the best part of the land itself, which, of course, is the fertile upper soil. Great furrows and gullies are cut across the fields, and the gravel and stones that are carried along are deposited in the lower country, and generally on the top of fertile bottom lands.

In the Southern Appalachians the fullest use of water resources can be secured only by carefully guarding the natural conditions which control them. The valuable water resources of this region depend absolutely upon the maintenance of a protective forest cover. Without this forest cover the water power of the region can never be developed to the full, and in the same way the navigable streams can not be kept from silting up if the forest cover about their headwaters is removed. The protection of these forests is a large undertaking, but it is necessarily the first undertaking, since it is fundamental to the development and utilization of the water resources. If the forest is not first protected damage to water resources will be far-reaching. If the forest is preserved the benefits from the standpoint of water utilization will be widely diffused, even far beyond the borders of the Appalachian region. It, therefore, is necessary that a forest system, similar to that which has accomplished so much toward conserving the forest and water resources of the West, be inaugurated in the Appalachian Mountains. Another urgent reason for protecting the forests on the Appalachian Mountains is the need of conserving the main center of hardwood supply of the United States and the industries which depend upon hardwoods. But the need of providing for the fullest development of water power is hardly secondary, and by itself would justify the extension to this region of the protection which is given through national forests in the West.

The following data are presented by the United States Geological Survey on the discharge of streams and the water storage facilities of the Southern Appalachian region, as related to the production of water power. The results are based on the data accumulated at the regular measurement stations maintained by the Survey during the past seven years, reenforced by special work carried on during the spring, summer, and fall of 1907. The schedules of water power are based on the minimum indicated horsepower developed in the rivers under consideration. In order to find this minimum horsepower the rivers were divided into sections of convenient length and of similar character, and the mean drainage area for each section was determined. The minimum flow per square mile for each section, based on seven-year records and auxiliary observations, was then calculated, and the indicated horsepower was deduced from the total slope of the channel. Additional estimates are given concerning the power which could be made available by storage. The location and capacity of reservoirs, together with other necessary facts, are shown in tabular form. Finally, there are given estimates of power based on lowest flow during the 6 highest months of the year. These estimates, as will be seen, are considerably higher than those based upon the minimum flow. They will serve to show what the commercially profitable development is likely to be. In this and other parts of the United States experience has shown that it pays to develop a water power up to the minimum that can be furnished during the 4 high-water months of the year, and to depend on steam power during low-water seasons to make up the deficiency. To make the present estimate conservative the limit of time has been extended to six months, and estimates are based upon that period.

Large allowances have been made in all the factors involved in the water power considerations. In all calculations of water power, only 90 per cent of the observed fall is used, and the indicated energy produced by the falling water is reduced to 80 per cent. It is believed that all the estimates can be used with safety, and in actual practice it will probably be found that in nearly every case the power available for development is considerably greater than that indicated.

Table 1 gives the names of rivers considered in this report and the minimum indicated horsepower developed in each.

TABLE 1.—*Rivers investigated.*

River.	Portion considered.	Minimum indicated horsepower
Potomac	Above tide, Washington, D. C	131,800
James	Above tide, Richmond, Va	155,000
Roanoke	Above tide, Weldon, N. C	131,000
Pedee	Above tide, Cheraw, N. C	171,300
Santee	Above junction of Wateree and Congaree	320,200
Savannah	Above Augusta, Ga	209,000
Chattahoochee	Above Columbus, Ga	145,000
Coosa	Above Wetumpka, Ala	180,000
Monongahela	Above mouth	58,900
Great Kanawha	do	335,000
Tennessee	Above Riverton, Ala	992,700
Total		2,829,900

The following paragraphs contain a discussion of the power possibilities on streams rising in the Southern Appalachian region.

RIVERS ON ATLANTIC SEABOARD.

POTOMAC RIVER.

The Potomac River basin is the northernmost of the coast basins which have their headwaters within the proposed Southern Appalachian National Forest. There are abundant sites for storage reservoirs in the upper drainage area, and to demonstrate the possibilities of increasing water power by such storage, certain sites have been selected and their capacities determined. This information will be used in connection with subsequent discussions. The facts are set forth in Table 2.

TABLE 2.—*Selected reservoir sites in the Potomac River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
North Fork, South Branch, Potomac River at Petersburg, W. Va.	460	1.12	520	18,550	460	134	7,600
North Fork, South Branch, Shenandoah River, Rockingham County, Va.	210	.84	180	6,910	210	92	3,410
North River, Rockingham County Va.	290	1.33	390	14,150	290	96	9,710
Middle River, Augusta County, Va.	180	1.33	240	6,190	140	100	4,250
South Fork, Shenandoah River, Rockingham County, Va.	500	1.42	710	2,290	50	40	3,930
South Fork, Shenandoah River, Rockingham County, Va.	200	1.42	280	10,420	200	95	7,150

The facts concerning the indicated horsepower along the main stream from tide water up to Harpers Ferry are set forth in Table 3.

TABLE 3.—*Indicated horsepower developed by Potomac River between tide water and Harpers Ferry.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Potomac River:										
From Mile 2 to Mile 5	*Miles* 3	*Sq. miles.* 11,500	*Sec. ft.* 2,070	*Sec. ft.* 4,830	*Feet.* 31	5,840	13,600	4,600	9,200	18,400
From Mile 5 to below Great Falls	7	11,450	2,060	4,810	23	4,310	10,000	3,410	6,820	13,640
At Great Falls	2	11,400	2,050	4,790	76½	14,250	33,300	11,300	22,600	45,200
From above Great Falls to Mile 21	7	11,300	2,030	4,750	18	3,320	7,770	2,670	5,340	10,680
From Mile 21 to Mile 49	28	10,400	1,870	4,370	32	5,440	12,700	4,740	9,480	18,960
From Mile 49 to Harpers Ferry	12	9,480	1,700	4,170	40	6,180	15,200	5,930	11,860	23,720
Total						39,340	92,570	32,650	65,300	130,600

Between Harpers Ferry and the junction of North and South branches, a distance of 108 miles, the average slope is 2.5 feet per mile, and over much of the way it is so gradual that the installation of large power plants would involve the construction of long and expensive canals. Indeed, the Chesapeake and Ohio Canal is a good illustration of what would be necessary. The facts concerning the slope, flow, and indicated horsepower developed by this section of the river are given in Table 4.

Table 4.—*Indicated horsepower developed by Potomac River between Harpers Ferry and the junction of North and South branches.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Potomac River:	*Miles.*	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
From Harpers Ferry to Mile 63	2	6,350	762	3,050	36	2,490	9,980	1,700	3,400	6,800
From Mile 63 to Dam No. 4	22	6,120	734	2,940	23	1,540	6,150	1,090	2,180	4,360
From Dam No. 4 to Dam No. 5	20½	5,420	650	2,600	32	1,890	7,560	1,510	3,020	6,040
From Dam No. 5 to Sir Johns Run	24½	4,520	543	2,170	45	2,220	8,860	2,130	4,260	8,520
From Sir Johns Run to Dam No. 6	5	4,070	489	1,960	24	1,070	4,280	1,140	2,280	4,560
From Dam No. 6 to Haurote	14	3,630	436	1,740	34	1,350	5,370	1,610	3,220	6,440
From Haurote to Pawpaw	13	3,190	383	1,530	32	1,110	4,450	1,510	3,020	6,040
From Pawpaw to below mouth of South Branch of Potomac	7½	3,010	361	1,450	20	656	2,640	945	1,890	3,780
Total						12,326	49,290	11,635	23,270	46,540

North Branch.—The North Branch is about 80 miles long, and has a total fall of about 2,570 feet, 1,000 feet of which occurs within 12 miles from the source. There is a minimum of 4,700 indicated horsepower developed by the main stream, and 1,870 by the tributaries. The greater part of this, however, could not be developed profitably at the present market price of power. The portion of the river best adapted for power is that between Abrams Creek and Cumberland. Along a distance of 44 miles there is a total fall of 1,060 feet. The average minimum discharge is 37 cubic feet per second, which will produce a minimum indicated horsepower of 3,170. The minimum developed during the 6 high-water months along this portion of the stream is 18,920 horsepower. In a distance of 7 miles below Cumberland there is a fall of 63 feet, which could be developed for a minimum of 480 horsepower, or, based on the 6 highest months, for 2,900 horsepower.

South Branch.—Various portions of this river are well adapted for the development of power. The minimum on the main stream and its tributaries is 15,207 indicated horsepower, while the minimum for the 6 highest months is 52,685 horsepower; only a small part of this could be profitably developed at the present rental price. The details concerning the main stream are given in Table 5:

TABLE 5.—*Indicated horsepower developed by South Branch of Potomac River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
South Branch, Potomac River:										
From mouth to Romney	*Miles.* 29.6	*Sq. miles.* 1,450	*Sec. ft.* 189	*Sec. ft.* 653	*Feet.* 114	1,960	6,770	5,400	10,800	21,600
From Romney to below junction Moorefield River	24	1,300	169	585	136	2,090	7,230	6,430	12,860	25,720
From above junction Moorefield River to below junction North Fork, South Branch, Potomac River	16½	770	100	347	155	1,410	4,890	4,250	8,500	17,000
From above junction North Fork South Branch Potomac River, to below junction Thorn Run	35	236	31	107	730	2,040	7,100	None.	None.	None.
From above junction Thorn Run to source	25	[a] 123	13	46	[b] 425	520	1,780	None.	None.	None.
Total						8,020	27,770	16,080	32,160	64,320

[a] Total area.

[b] 25 per cent total fall.

Shenandoah River.—Along the main stream of the Shenandoah there is a minimum of 31,970 indicated horsepower available for development. The minimum for the 6 highest months is 63,540 horsepower.

Among the other tributaries of the Potomac on which considerable horsepower is available are the following:

South River, a tributary of the South Fork of the Shenandoah, is 50 miles long, and has a fall of 1,950 feet. In the lower 22 miles there is a fall of 250 feet, with a minimum indicated horsepower of 1,020. The minimum for the 6 highest months is 1,940 horsepower. South Fork of the Shenandoah is 101 miles long, and has a total fall of 576 feet. There is developed a minimum indicated horsepower of 17,690, while the minimum for the 6 highest months of the year is 34,390 horsepower. In the first 17 miles above the mouth of the river there is a total fall of 70 feet, with a minimum horsepower of 2,640. The minimum for the 6 highest months is equivalent to 5,170 horsepower. In the next 20 miles there is a total fall of 114 feet and a minimum indicated horsepower of 3,940, while the minimum for the next 15 miles is 2,330 horsepower. Above this there is a section 9 miles long with a fall of 63 feet and a minimum of 1,860 indicated horsepower. On the North Fork of the Shenandoah the conditions are similar to those on the South Fork. The portion of the stream best adapted to power development is the lower section of 48 miles. This section has a fall of 390 feet and a minimum flow of 152 cubic feet per second, the energy of which is represented by 4,860 horsepower. The minimum for the 6 highest months is 9,720 horsepower.

Along the main stream of the Shenandoah there are several good power sites. The facts concerning this portion of the river appear in Table 6.

TABLE 6.—*Indicated horsepower developed by Shenandoah River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Shenandoah River:										
From mouth (Harpers Ferry) to Cattail Run	*Miles.* 6	*Sq. miles.* 3,010	*Sec. ft.* 720	*Sec. ft.* 1,540	*Feet.* 41	2,680	5,740	4,140	8,280	16,560
From Cattail Run to Mile 7	2	3,000	720	1,530	32	2,090	4,450	3,230	6,460	12,920
From Mile 7 to Mile 27½	20½	2,900	700	1,480	44	2,800	5,920	4,440	8,880	17,760
From Mile 27½ to Mile 39½	12	2,750	690	1,380	30	1,880	3,760	3,030	6,060	12,120
From Mile 39½ to Wilson's Mill	9½	2,670	670	1,310	31	1,890	3,690	3,130	6,260	12,520
Total						11,340	23,560	17,970	35,940	71,880

There are, of course, many sites on smaller tributaries at which powers could profitably be developed. The nature of this paper does not allow of their further mention here, but information concerning them can be obtained by addressing the United States Geological Survey.

JAMES RIVER.

The basin of the Potomac adjoins the James River basin. The drainage area of the James River above Richmond, Va., is 6,790 square miles in extent, and its length from tide to source at the head of Jackson River is 315 miles. Its minimum flow varies from 0.19 to 0.41 cubic foot per second per square mile. Among the many reservoir sites in the drainage area, those shown in Table 7 have been selected as the best combination.

TABLE 7.—*Selected reservoir sites in the James River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Sq. mi.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Sq. mi.*	*Feet.*	*Acres.*
Jackson River, west Bath County, Va.	300	1.18	350	12,400	300	124	5,100
Cowpasture River, Bath County, Va.	280	1.18	330	10,700	280	118	4,300
North River, Rockbridge County, Va.	210	1.18	250	8,620	210	137	5,440
Calfpasture River, southwest Augusta County, Va.	120	1.18	140	4,140	110	100	2,850
James River, Botetourt County, Va.	1,060	1.18	1,250	43,890	1,060	135	18,470
Buffalo Creek, Rockbridge County, Va.	80	1.18	90	3,660	80	113	1,980
Johns Creek, Newcastle, Va.	90	1.18	110	4,620	90	123	3,120

The main stream between Richmond and Eagle Mountain, a distance of about 215 miles, has a rapid fall and many promising sections for power development.

Jackson River, which is the upper extension of the James, is 83 miles long. Between its source and the head of the James there is a fall of 2,150 feet. Along the first 14-mile section above Clifton Forge there is a fall of 170 feet. The mean catchment drainage area is 816 square miles, with a minimum discharge of 204 cubic feet per second. There is a minimum horsepower of 2,840. The lowest flow for the 6 high-water months develops 5,450 horsepower. Above this section between Dunlap and Potts Creek there is a fall of 30 feet in a distance of 4 miles, equivalent to a minimum horsepower of 392, or a minimum for the 6 highest months of 770. The increase from storage during six months would be 1,720 horsepower. A statement of the prevailing conditions is given in Table 8.

TABLE 8.—*Indicated horsepower developed by James River between Richmond and Eagle Mountain and by Jackson River between Clifton Forge and Back Creek.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
James River:										
From Richmond to Lorraine....	*Miles.* 14	*Sq. miles.* 6,770	*Sec. ft.* 2,780	*Sec. ft.* 3,660	*Feet.* 112	28,300	37,300	25,600	51,200	102,400
From Lorraine to Irwin.......	21.5	6,610	2,710	3,570	25	6,160	8,110	5,720	11,400	22,800
From Irwin to Columbia......	23.5	6,160	2,530	3,330	34	7,820	10,300	7,780	15,600	31,200
From Columbia to Payne......	18	5,200	1,720	2,550	63	9,850	14,600	14,400	28,800	37,600
From Payne to Howardsville..	16	4,500	1,260	2,030	38	4,360	7,000	8,700	17,400	34,800
From Howardsville to Warminster........	9	4,320	1,170	1,900	27	2,870	4,660	6,180	12,400	24,800
From Warminster to Greenway...........	14	3,940	950	1,660	40.5	3,500	6,110	9,280	18,600	37,200
From Greenway to Riverville...	9	3,650	800	1,500	34	2,470	4,640	7,780	15,600	31,200
From Riverville to Joshua Falls Dam.....	12.5	3,550	780	1,420	42	2,980	5,420	9.620	19,200	38,500
From Joshua Falls Dam to Lynchburg....	11.5	3,440	722	1,380	45	2,960	5,650	10,300	20,600	41,200
From Lynchburg to Big Island..........	18	3,230	646	1,290	85	5,000	10,000	19,500	39,000	78,000
From Big Island to Balcony Falls...........	9	3,060	612	1,190	86	4,790	9,310	19,700	39,500	79,000
From Balcony Falls to Varney Falls......	10	2,180	414	828	48	1,800	3,610	8,900	17,800	35,600
From Varney Falls to Buchanan.........	11	2,100	400	798	58	2,110	4,210	10,750	21,500	43,000
From Buchanan to Saltpeter Cave...........	10	2,010	382	765	62	2,150	4,310	11,500	23,000	46,000
From Saltpeter Cave to Eagle Mountain......	8	1,890	360	737	41	1,340	2,750	2,040	4,080	8,160
Jackson River:										
From above Clifton Forge to below junction Potts Creek....	14	816	204	392	153	2,840	5,450	4,000	8,000	16,000
From above junction Potts Creek to below junction Dunlap Creek......	4	613	160	313	27	392	770	860	1,720	3,440
From above junction Dunlap Creek to below junction Back Creek....	27	367	99	198	428	3,850	7,700	13,600	27,250	54,500
Total.......	......	....	....	....	......	95,542	151,900	196,210	392,650	765,400

Tributaries.—The tributaries of James River have steep courses; the drainage areas are comparatively large, and the summer flow is considerable. North River, the largest tributary, has a total drainage area of 831 square miles. The section from Rockbridge bar to the mouth, 34 miles long, has a total fall of 390 feet and a minimum run-off of 140 cubic feet per second, which will develop 4,470 minimum horsepower. Many places along this stream would be suitable for small installations. Riviana River, another tributary, has a drainage area of 774 square miles. In the 51 miles between the mouth of Moormans River and the James, there is a fall of 210 feet, and the minimum run-off is estimated at 331 cubic feet per second. If 189 feet of this fall were developed there would be a minimum of 5,680 horsepower.

ROANOKE RIVER.

On the south the basin of the Roanoke adjoins that of the James. Consideration of available power is confined to that part of the river above Weldon, N. C., which is the head of important navigation. Above this point the river has a drainage area of 8,620 square miles. Its length, by way of South Fork, to the head of Bottom Creek, is 272 miles, and the amount of water carried in the channel is equivalent to from 0.25 to 0.47 cubic foot per second per square mile; that is, each square mile of drainage area contributes a minimum flow of that amount of water. There are excellent storage facilities in the basin; if these are properly developed it will be possible to control the flow of the river to an unusual degree and to increase its value enormously. The reservoir sites shown in Table 9 have been selected as representing an excellent combination for such purposes.

TABLE 9.—*Selected reservoir sites in the Roanoke River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Sq. miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Sq. miles.*	*Feet.*	*Acres.*
North Fork, Roanoke River, east Montgomery County, Va.	120	1.23	150	4,820	120	125	2,170
South Fork, Roanoke River, southeast Montgomery County, Va.	110	1.23	140	4,600	110	140	1,790
Goose Creek, Bedford County, Va.	260	1.23	320	10,200	260	106	6,560
Roanoke River, Bedford County, Va.	760	1.23	930	29,700	760	150	15,000

The main stem of the Roanoke, from Weldon, N. C., to the junction of North and South forks, is 249 miles long, and has a total fall of 1,225 feet. The average slope is, therefore, 5 feet per mile. The fall is not uniform, however, and there are many precipitous slopes which afford favorable sites for power development. The indicated horsepower along the river, as shown in chosen sections, is set forth in Table 10.

TABLE 10.—*Indicated horsepower developed by Roanoke River between Weldon, N. C., and junction of North and South forks.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Roanoke River:										
From Weldon (Mile 0) to Mile 6	*Miles.* 6	*Sq. miles.* 8,600	*Sec. ft.* 3,960	*Sec. ft.* 6,450	*Feet.* 50	18,000	29,300	7,000	14,000	28,000
From Mile 6 to Mile 12	6	8,580	3,950	6,440	34	12,200	19,900	4,750	9,500	19,000
From Mile 12 to Mile 29	17	8,500	3,910	6,380	49	17,400	28,400	6,850	13,700	27,400
From Mile 29 to Mile 46	17	8,250	3,790	6,190	22.5	7,750	12,700	3,150	6,300	12,600
From Mile 46 to Mile 58	12	7,970	3,670	5,980	23.5	7,840	12,800	3,290	6,580	13,200
From Mile 58 to Clarksville	12	7,600	3,500	5,700	47	14,950	24,400	6,600	13,200	26,300
From Clarksville to Mile 104.5	34.5	3,300	1,550	2,440	55	7,750	12,200	7,700	15,400	30,800
From Mile 104.5 to Scotts Ferry	22	2,750	1,240	1,950	35	3,950	6,200	4,900	9,800	19,600
From Scotts Ferry to Mile 132	5.5	2,430	1,020	1,630	37	3,430	5,480	5,200	10,400	20,700
From Mile 132 to Clements Falls	25.5	2,080	770	1,310	97	6,790	11,600	13,600	27,200	54,300
From Clements Falls to below junction Pig River	22.5	1,590	508	920	64	2,950	5,350	7,800	15,600	31,100
From below junction Pig River to Smith Mountain Gap	4.3	1,219	342	659	15.3	476	916	1,695	3,390	6,780
From Smith Mountain Gap to Turners Ford	20.7	849	221	416	90	1,810	3,400	Obliterated by proposed reservoir.		
From Turners Ford to Mile 219	14	632	158	291	69	990	1,820	920	1,840	3,690
From Mile 219 to below junction Tinker Creek	7	546	137	246	95	1,180	2,130	2,500	5,000	10,000
From below junction Tinker Creek to 1 mile above Salem	12.5	410	102	193	110	1,020	1,930	2,900	5,800	11,600
From 1 mile above Salem to junction North Fork of Roanoke River	11	283	74	136	207	1,390	2,560	5,450	10,900	21,800
Total						109,876	181,086	84,305	168,610	336,870

Tributaries.—The principal tributary of the Roanoke, the Dan River, is not included in these estimates, because its drainage area lies almost entirely below the Southern Appalachian region proper. The principal value of the rest of the tributaries of the Roanoke lies in the fact that they are contributors to the main stream. They do not afford many power sites, although there are some good ones of limited capacity. Otter River, between Little Otter River and the mouth, is 18 miles long and has a total fall of 90 feet. The minimum indicated horsepower is 1,430, and that for the 6 high-water months 2,150. Goose Creek below the junction of Wolf Creek is 21 miles long and has a fall of 125 feet, which would develop 985 horsepower for a minimum, or 1,380 horsepower for the 6 high-water months. The lower 23 miles of Blackwater River has a fall of 230 feet, which if all developed would produce 1,260 horsepower, or a minimum for the 6 high-water months of 2,520 horsepower. The development of all of these tributaries would, however, be quite expensive.

PEDEE RIVER (YADKIN).

That part of the Pedee system here considered for power development lies entirely above Cheraw, S. C., which is the head of extensive navigation. The total length above Cheraw is 253 miles. The name Pedee is given to the river up to the mouth of the Uharie River. Above this point the river is called the Yadkin.

Among the many reservoir sites in the Yadkin basin those shown in Table 11 have been selected as the most effective combination:

TABLE 11.—*Selected reservoir sites in the Yadkin River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Yadkin River, Wilkesboro, N. C.	500	2.72	1,360	42,050	480	130	22,600
Yadkin River at Elkville, N. C.	230	2.72	620	20,300	230	140	10,100
South Yadkin River, Davie County, N. C.	730	2.72	2,000	20,500	230	80	15,600
Deep Creek, Yadkinville, N. C.	120	2.72	330	9,400	110	100	6,600
Ararat River, Surrey County, N. C.	290	2.72	790	5,300	60	100	3,700

The distance from Cheraw, S. C., to the mouth of Uharie River is 73 miles. The first 60 miles, from Cheraw to Allentown Ferry, has a fall of 136 feet and an average minimum discharge of 2,320 cubic feet per second. This will produce a minimum indicated horsepower of 25,800. There are numerous shoals along this section, and a large proportion of the indicated power could actually be developed. This is also true of the next section of 13 miles between Allentown Ferry and Uharie River. The fall is 38 feet, the minimum flow 2,300 cubic feet per second, and the indicated minimum horsepower 7,160. The minimum for the 6 highest months on the lower section is 38,800, and that for the upper section 10,700 indicated horsepower. The increase from storage would be as follows:

Lower section—37,400 horsepower for one year, 74,800 horsepower for six months, and 149,600 horsepower for three months.

Upper section—10,400 horsepower for one year, 20,800 horsepower for six months, and 41,600 horsepower for three months.

The indicated horsepower along designated sections of the Yadkin, from the mouth of Uharie River to Buffalo Creek, is given in Table 12.

Table 12.—*Indicated horsepower developed by Yadkin River between the mouth of Uharie River and Buffalo Creek.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Yadkin River:										
	Miles	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
From Uharie River to Salisbury	47	3,650	2,010	3,020	380	69,400	104,000	116,000	232,000	464,000
From Salisbury to South Yadkin River	4	3,400	1,980	2,970	5	972	1,460	1,650	3,300	6,600
From South Yadkin River to Ararat River	45	2,000	1,400	2,100	117	14,800	22,300	26,400	52,800	105,600
From Ararat River to Roaring River	33	970	776	1,160	146	10,300	15,400	26,200	52,400	104,800
From North Wilkesboro to Buffalo Creek	25	240	264	396	212	5,080	7,610	5,640	11,280	22,560
Total						100,552	150,770	175,890	351,780	703,560

Tributaries.—The drainage areas of the tributaries of Yadkin River are generally too limited to be important for power development, although the total energy produced in them is considerable. South Yadkin River, for example, has a length of 51 miles. There is a total fall of 618 feet and a minimum discharge of 262 cubic feet per second, giving an indicated minimum horsepower of 4,240. Ararat River, 35 miles long, has a fall of 700 feet. Considering a mean head of 207 feet and a minimum discharge of 230 cubic feet per second, there is an indicated horsepower of 4,330. A large part of the power on both streams would be obliterated by the construction of the proposed South Yadkin and Ararat reservoirs. Conditions on the rest of the important tributaries of the Yadkin are similar. They are summed up in Table 13:

TABLE 13.—*Indicated horsepower developed by tributaries of Yadkin River (except South Yadkin and Ararat rivers.)*

Section of river.	Length.	Total drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
	Miles.	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*						
Fisher River, from mouth to head...	32	151	107	160	270	2,630	3,940	None.	None.	None.
Mitchell River, from mouth to head............	20	108	92	138	290	2,420	3,630	None.	None.	None.
Roaring River, from mouth to head............	17	130	107	160	260	2,530	3,800	None.	Power slightly reduced by Wilksboro Res.	
Mulberry River, from mouth to head............	16	42	42	63	270	1,030	1,540	None.	Power slightly reduced by Wilksboro Res.	
Reddie River, from mouth to head............	20	92	107	160	345	3,360	5,040	None.	Power slightly reduced by Wilksboro Res.	
Louis Fork, from mouth to head...	13	73	70	105	425	2,700	4,050	None.	None.	None.
Stony Creek, from mouth to head...	12	35	42	63	500	1,910	2,860	None.	Power slightly reduced by Elksville Res.	
Elk River, from mouth to head...	16	51	61	92	370	2,050	3,080	None.	Power slightly reduce by Elksville Res.	
Total.......	.....	....	....	....	......	18,630	27,940			

SANTEE RIVER.

The Wateree and the Congaree rivers join to form the Santee 180 miles above its mouth. The Santee proper is a navigable stream, with comparatively little fall, so that power is considered only for the area above the fork. On the Wateree the section between the mouth and Camden will not be considered.

CATAWBA RIVER.

Table 14 gives detailed facts concerning the storage facilities at the headwaters of Catawba River, which is the name given to the Wateree above the mouth of Wateree Creek.

TABLE 14.—*Selected reservoir sites in the Catawba River Basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Sq. mi.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Sq. mi.*	*Feet.*	*Acres.*
Catawba River, northwest Mecklenburg County, N. C............	430	1.64	700	24,970	430	77	18,250
Catawba River, near Hickory, Catawba County, N. C...........	600	1.64	980	9,870	190	100	7,670
Catawba River, west of Morganton, N. C........................	480	1.64	790	5,380	100	75	4,920

The indicated horsepower developed by the Wateree and its tributaries is as follows:

The section from Camden to the mouth of Wateree Creek, 17 miles, has a total fall of 75 feet. The mean drainage area is 4,200 square miles, and the minimum flow 2,180 cubic feet per second. This will develop a minimum indicated horsepower of 13,400, or a minimum for the 6 highest months of 20,200. The storage indicated in the above table will increase the indicated horsepower for the section as follows: 8,050 for one year, 16,100 for six months, and 32,200 for three months. The greater part of this fall is concentrated in the 6½ miles beginning with the foot of Hoke Shoals. The available fall here is about 65 feet. This would produce a minimum of 11,600 horsepower, or a minimum for the 6 high-water months of 17,300. The increase by storage would amount to about 7,000 horsepower if evenly distributed over a period of twelve months.

The indicated horsepower produced by the main stem of the Catawba from the mouth of Wateree Creek to the mouth of North Fork, together with facts relating thereto, is shown in Table 15.

TABLE 15.—*Indicated horsepower developed by Catawba River between the mouth of Wateree Creek and the mouth of North Fork.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Catawba River:										
	Miles	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
From Wateree Creek to Catawba, S. C.	29	3,650	2,010	3,020	252	46,100	69,100	30,000	60,000	120,000
From Catawba, S. C., to Little Catawba River.	28	3,100	1,860	2,790	36	6,080	9,090	4,300	8,600	17,200
From Little Catawba River to Catawba, N. C	60	1,870	1,220	1,830	207	22,900	34,400	13,550	27,100	54,200
From Catawba, N. C., to John River	46	1,270	889	1,340	207	16,700	25,100	3,500	7,000	14,000
From John River to Linnville River	77	780	585	878	68	3,590	5,380	Greatly reduced by proposed Hickory Reservoir.		
From Linnville River to North Fork	17	460	345	518	117	3,670	5,510	Obliterated by proposed Morganton Reservoir.		
Total						99,040	148,580	51,350	102,700	205,400

It should be noted in connection with Table 15 that in all sections above Little Catawba the indicated power will be obliterated or modified by the construction of the reservoirs described in Table 14. For example, in the section between Little Catawba River and John

River a part of the river bed would be largely covered by the proposed reservoirs. This would, of course, obliterate the natural slope of the river at some sections, so far, at least, as it may be available for power development, and would concentrate the fall at the dam sites. The statements of increase of power from storage in the river above the mouth of Little Catawba have been adjusted to meet these changes in available fall.

CONGAREE RIVER.

Congaree River, which, as has been explained, unites with the Wateree to form the Santee, is in turn formed at Columbia, S. C., a few miles above its mouth, by the junction of the Broad and Saluda rivers. No report can be made at the present time concerning the storage facilities for these areas, owing to the want of surveys. For this reason the additional power which might be derived from storage will not be considered in discussing the water power in the Congaree basin.

BROAD RIVER.

From the junction of the Broad and Saluda rivers, down the Congaree 2 miles, there is a fall of 7 feet which might be somewhat increased by the construction of a diversion dam 10 or 12 feet high. Considering only the natural fall, there is derived from the 7,300 square miles of drainage area and the minimum flow of 3,650 cubic feet per second a minimum indicated horsepower of 2,090, which could be greatly increased by the development of storage facilities on the drainage area above.

The minimum indicated horsepower developed along the Congaree and Broad rivers, together with related facts, is set forth in Table 16.

TABLE 16.—*Indicated horsepower developed by Congaree and Broad rivers.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
	Miles	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
Congaree River from Granky to Broad (Saluda) River	2	7,300	3,650	5,480	6	2,090	3,130	Not ascertained.		
Broad River:										
From mouth to Alston	25	4,800	2,640	3,960	81	19,400	29,200	Not ascertained.		
From Alston to Gaffney	80	3,000	1,800	2,700	288	47,200	70,700	Not ascertained.		
From Gaffney to Green River	36	1,000	700	1,050	196	12,500	18,700	Not ascertained.		
From Green River to Cove Creek	18	230	184	276	36	602	900	Not ascertained.		
From Cove Creek to head	24	[a] 106	106	159	[b] 740	7,130	10,700	Not ascertained.		
Total						88,922	133,330			

[a] Total area.

[b] Mean head.

Tributaries of Broad River.—Many excellent sites for power development may be found on the tributaries of Broad River. From the head to the mouth of First Broad River, for example, a distance of 35 miles, there is a total fall of 900 feet, of which it is estimated that 320 feet is a fair amount to use for calculation of available power. The drainage area at the mouth is 275 square miles, and the minimum discharge 275 cubic feet per second, which will develop an indicated horsepower of 8,000. On the Second Broad River, in the 17 miles from the mouth to Logans Store, there is a fall of about 240 feet, which will develop an indicated horsepower of 2,940.

SALUDA RIVER.

Facts concerning the indicated horsepower on the Saluda River and its principal tributaries are set forth in Table 17.

TABLE 17.—*Indicated horsepower developed by Saluda River and principal tributaries.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Saluda River:										
From mouth to Southern Railway, Chappells.	*Miles.* 60	*Sq. miles.* 1,900	*Sec. ft.* 1,040	*Sec. ft.* 1,560	222	21,100	31,600	Not ascertained.		
From Southern Railway, Chappells, to Southern Railway, Piedmont.	65	900	585	878	329	17,600	18,200	Not ascertained.		
From Southern Railway, Piedmont, to Southern Railway, Greenville	10	350	245	368	54	1,210	1,810	Not ascertained.		
From Southern Railway, Greenville, to North Saluda River..........	10	270	202	303	81	1,480	2,230	Not ascertained.		
From North Saluda River to South Saluda River..........	5	160	144	216	36	472	707	Not ascertained.		
North Saluda River, from mouth to head........	22	[a] 77	77	116	[b] 263	1,840	2,760	Not ascertained.		
Middle Saluda River, from mouth to head..	15	[a] 50	50	75	[b] 400	1,820	2,730	Not ascertained.		
South Saluda River, from mouth to head..........	20	[a] 100	100	150	[b] 250	2,270	3,400	Not ascertained.		
Total..........	......	....	....	....	....	47,792	63,437	....	....	....

[a] Total area.

[b] Mean head.

SAVANNAH RIVER.

Savannah River is formed by the junction of the Seneca and Tugaloo rivers at Andersonville, S. C., 245 miles above the mouth, or 100 miles above Augusta, Ga. Tugaloo River is, in turn, formed by the junction of the Tallulah and the Chattooga, 48 miles above the junction of the Tugaloo and Seneca. In this paper the discussion of water power on the Savannah River is confined to the part of the drainage area lying above Augusta. The drainage area of Savannah River above this point is 7,300 square miles. The headwaters are well suited to the development of storage reservoirs, and from those parts of the basin upon which surveys have been made there have been selected a number of reservoir sites, the characteristics of which are set forth in Table 18.

TABLE 18.—*Selected reservoir sites in the Savannah River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Keowee River, Pickens County, S. C.	270	3.45	930	25,130	230	150	11,240
Little River, Oconee County, S. C.	90	3.45	310	8,480	80	100	5,820
Twelve-Mile Creek, Pickens County, S. C.	160	3.45	550	2,210	20	50	3,030
Twenty-three Mile Creek, Anderson County, S. C.	150	3.45	520	15,370	140	70	6,620
Conneross Creek, Oconee County, S. C.	80	3.45	280	1,700	20	50	2,330
Tugaloo River, southwest Oconee County, S. C.	260	3.45	900	11,870	110	100	8,140
Chattooga River, west Oconee County, S. C.	120	3.45	410	9,470	90	150	3,310
Chattooga River, west Oconee County, S. C.	190	3.45	660	15,920	140	150	4,690
Tallulah River, Rabun County, Ga.	130	4.35	570	2,440	20	90	1,860
South Fork River, Oglethorpe County, Ga.	260	1.89	490	1,940	30	50	2,060
Broad River, Madison County, Ga.	440	1.89	830	28,590	440	98	17,850
Hudson River, Banks County, Ga.	180	1.89	340	4,680	80	50	6,420
Beaver Dam Creek, east of Elberton, Ga.	110	1.89	210	7,030	110	98	3,960
Rocky River, near Lowndesville, S. C.	240	1.89	450	9,680	160	100	6,580

That part of the Savannah River lying between Augusta, Ga., and the mouth of Seneca River, 100 miles long, has been divided into 5 sections for the purpose of considering indicated power as shown in Table 19.

TABLE 19.—*Indicated horsepower developed by Savannah River between Augusta, Ga., and Seneca River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Savannah River:										
From Augusta, Ga., to head of dam	*Miles* 7	*Sq. miles.* 7,000	*Sec. ft.* 4,200	*Ser. ft.* 6,300	*Feet.* 40	15,500	23.200	18,200	36,400	72,800
From head of dam to Little River, S. C	30	5,800	3,770	5,660	95	32,700	49,000	43,000	86,000	172,000
From Little River, S. C., to Broad River	16	4,700	3,290	4,940	21	6,190	9,270	9,300	18,600	37,200
From Broad River to Seaboard Air Line bridge	12	2,800	2,240	3,360	81	16,500	24,700	28,000	56,000	112,000
From Seaboard Air Line bridge to Seneca River	35	2,220	2,000	3,000	121	22,000	32,900	35,500	71,000	142,000
Total						92,890	139,070	134,000	268,000	536,000

TUGALOO RIVER.

In Tugaloo River, there is a section between the mouth of the river and Madison, 33 miles in length, along which there is a fall of 135 feet. The mean drainage area is 790 square miles, and the minimum flow 790 cubic feet per second, which would produce a minimum indicated horsepower of 8,730, or a minimum for the 6 highest months of 13,100. This would be increased by storage to 14,000 horsepower if distributed evenly over one year, or to 28,000 if utilized during a low-water season of six months. The next section, between Madison, S. C., and the mouth of Tallulah River, is 15 miles long, with a total fall of 114 feet. The mean drainage area is 530 square miles, which produces a minimum run-off of 689 cubic feet per second. This will afford a minimum indicated horsepower of 6,430, or a minimum for the 6 highest months of 9,630. The increase from storage facilities would be 8,240 if distributed over twelve months, or 16,480 for a six months' period. The greatest fall is in the upper portion of this section. In the 8 miles from the junction of Tallulah and Chattooga rivers down to Big John Creek there is a total fall of 104 feet.

CHATTOOGA RIVER.

Chattooga River is 39 miles long from its confluence with the Tallulah to the head of West Fork. The indicated horsepower developed and the facts relating thereto are shown in Table 20.

TABLE 20.—*Indicated horsepower developed by Chattooga River between its confluence with the Tallulah and West Fork.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Chattooga River:										
From Tallulah River to Stekoa Creek......	*Miles* 7	*Sq. miles.* 265	*Sec. ft.* 400	*Sec. ft.* 600	*Feet.* 266	9,630	14,400	Submerged.		
From Stekoa Creek to Clayton Station....	3	210	315	472	105	3,020	4,520	5,320	10,640	21,280
From Clayton Station to Warwoman Creek..........	13	189	285	428	[a]288	7,460	11,200	1,500	3,000	6,000
From Warwoman Creek to West Fork....	8	125	188	282	69	1,190	1,780	Submerged.		
Total........	......	....	....	....	......	21,300	31,900	6,820	13,640	27,280

[a] Fall reduced to about 33 feet by proposed reservoirs.

As Table 20 shows, the course of Chattooga River is steep, and it is probable that in the actual economical development of the power available all the fall could be utilized. In other words, the indicated horsepower represents the actual minimum available.

Tributaries of Chattooga River.—North Fork, from its mouth to its head, is 8 miles long and has a total fall of 1,000 feet. Considering 440 feet of this fall as available for development there would be produced 3,360 minimum horsepower. West Fork also is 8 miles long from its mouth to its head. There is a mean head of 300 feet, which, with a discharge of 93 cubic feet per second, would produce a minimum of 2,540 horsepower. Several good opportunities for small power installation are afforded by Toccoa and Brasstown creeks and Chauga River, tributaries of Tugaloo River. Stekoa Creek from its junction with Chattooga River to its head, a distance of 9 miles, has a total fall of 900 feet and a mean head of 500 feet, which will produce an indicated minimum horsepower of 2,640, or a minimum for the 6 highest months of 3,960.

Warwoman Creek, a tributary of Chattooga River, is 7 miles long, and has a total fall of 600 feet, and a mean head of 305, which will produce a minimum horsepower of 1,750, with a minimum for the 6 highest months of 2,620.

TALLULAH RIVER.

Tallulah River from head to mouth is about 44 miles long. Along the lower 35 miles there is a total fall of 716 feet, of which probably 90 per cent could be utilized. In other words, the indicated horsepower for this 35 miles is the same as the power actually available for economic development. The facts are given in Table 21.

TABLE 21.—*Indicated horsepower developed by Tallulah River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Tallulah River:										
From mouth to foot of Tallulah Falls	*Miles* 2.5	*Sq. miles.* 192	*Sec. ft.* 259	*Sec. ft.* 388	*Feet.* [a] 229	5,380	8,070	760	1,520	3,040
From foot of Tallulah Falls to head of falls	1	191	260	390	365	8,640	13,000	2,950	5,900	11,800
From bridge at head of falls to 2 miles above falls	2	188	257	386	130	3,050	5,380	1,060	2,120	4,240
From 2 miles above falls to Persimmon Creek	29	133	186	279	[b] 280	4,730	7,100	800	1,600	3,200
From Persimmon Creek to head	10	[c] 61	85	128	[d] 330	2,550	3,820	None.	None.	None.
Total	......	....	....	....	......	24,350	37,370	5,570	11,140	22,280

[a] Fall reduced to 104 feet by proposed upper Chattooga reservoir.
[b] Fall reduced to 110 feet by Tallulah reservoir.
[c] Total area.
[d] Mean head.

SENECA RIVER.

Along the first section of 22 miles of Seneca River, viz, from the mouth to Twelve-Mile Creek, there is a rise of about 135 feet. The mean drainage area of 780 square miles produces a minimum discharge of 749 cubic feet per second, which will produce a minimum horsepower of 8,270, or a minimum for the 6 highest months of 12,400. The next section, 5 miles long, lying between the mouth of Twelve-Mile Creek and the confluence of Little and Keowee rivers, has a total fall of about 30 feet, and a minimum discharge of 460 cubic feet per second, which will provide a minimum indicated horsepower of 1,130 and a minimum for the 6 highest months of 1,700. Keowee River, a tributary of the Seneca, 15 miles long from its mouth to the mouth of White Water Creek, has a total fall of 140 feet, which will produce a minimum indicated horsepower of 2,860. White Water Creek, above mentioned, along its lower 5 miles, has a fall of 80 feet, with a minimum discharge of 150 cubic feet per second, which will produce a minimum of 981 indicated horsepower. The remaining 6 miles of White Water River has a total fall of about 2,500 feet, and the mean working head for power development has been considered as 1,200 feet. The minimum discharge is 60 feet per second, which will provide for a minimum of 6,540 indicated horsepower, or a minimum during the 6 highest months of 9,810. This is an exceptionally good power stream for comparatively small installation. Twelve-Mile Creek, another tributary of the Seneca, is 26 miles long from mouth to head, and has a mean fall of 300 feet, which will produce a minimum indicated horsepower of 4,140. Other tributaries of the Seneca are Little River, with a working head of 180 feet and a minimum indicated horsepower of 2,700; also, Estatoe Creek, with a working head of 340 feet and a minimum indicated horsepower of 1,850. Horsepasture River, a tributary of the White Water, is 20 miles long from mouth to head. The total working head for power development is about 1,430 feet, which will produce a minimum indicated horsepower of about 6,650, with a proper distribution of the unit.

CHATTAHOOCHEE RIVER.

Consideration of power in the Chattahoochee basin is confined to that part of the drainage area above Columbus, Ga., at which point the river has a drainage area of 4,900 square miles. The distance to the head of the river is 263 miles. Table 22 gives a statement concerning reservoir sites in the basin, and their capacities.

TABLE 22.—*Selected reservoir sites in the Chattahoochee River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cubic feet.*	*Square miles.*	*Feet.*	*Acres.*
Chattahoochee River north of Gainesville, Ga.	350	2.34	820	24,360	320	140	11,110
Chestatee River northwest of Gainesville, Ga.	140	2.34	330	10,640	140	100	7,300
Chestatee River east of Dahlonega, Ga.	150	2.34	350	3,300	40	100	2,260
Chattahoochee River east of White County, Ga.	110	2.34	260	5,520	70	100	3,790

The facts concerning indicated horsepower in the various sections from Columbus to Santee Creek are set forth in Table 23.

TABLE 23.—*Indicated horsepower developed by Chattahoochee River between Columbus and Santee Creek.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Chattahoochee River:										
From Columbus to West Point.	*Miles.* 35	*Sq. miles.* 4,100	*Sec. ft.* 2,100	*Sec. ft.* 3,360	*Feet.* 325	62,000	99,000	44,600	89,200	178,400
From West Point to Franklin	38	....	1,800	2,880	68	11,100	17,700	9,300	18,600	37,200
From Franklin to Oakdale	65	....	1,500	2,400	101	13,800	22,000	13,800	27,600	55,200
From Oakdale to Roswell	17	1,450	1,280	2,050	101	11,700	18,700	13,800	27,600	55,200
From Roswell to Norcross	13	1,200	1,100	1,760	28	2,790	4,460	3,800	7,600	15,200
From Norcross to Chestatee River	27	1,040	1,040	1,660	63	5,960	9,540	8,650	17,300	34,600
From Chestatee River to Soque River	40	450	540	864	[a]168	8,260	13,200	2,950	5,900	11,800
From Soque River to Leaf Station	3	152	228	365	71	1,480	2,360	1,220	2,440	4,880
From Leaf Station to Santee Creek	10	130	195	292	84	1,480	2,230	1,440	2,880	5,760
Total	.....	....	....	....	......	118,570	189,190	99,560	199,120	398,240

[a] Fall reduced to 65 feet by proposed Gainesville reservoir.

Tributaries.—The Chestatee River, an important tributary of the Chattahoochee, is 56 miles long and has a total drainage area of 320 square miles. The lower 18 miles of the river have a fall of 120 feet, and, as the minimum discharge of the section is 336 cubic feet per second, the indicated horsepower is 3,300 and the minimum for the 6 highest months would be 4,950 horsepower. The increase from storage would be 1,880 horsepower with full reservoir capacity distributed over six months, although the fall would be reduced to 24 feet by the Chestatee reservoir. The next 19 miles from the top of the dam at New Bridge has a fall of 145 feet, which would develop an indicated horsepower of 2,840. Another important tributary of the Chattahoochee is the Soque, which in 6 miles has a fall of 116 feet and a minimum discharge of 197 cubic feet per second. This will produce a minimum indicated horsepower of 1,870, or a minimum for the 6 highest months of 2,800.

COOSA RIVER.

The Alabama River, a tributary of the Mobile River system, is formed by the junction of the Coosa and Tallapoosa rivers, a few miles above Montgomery, Ala. In this paper the consideration of power is confined to the Coosa River drainage area. The Coosa

River forks at Rome, Ga., and above this point the south branch is known as the Etowah and the north branch as the Oostanaula. The characteristics of selected reservoir sites are set forth in Table 24.

TABLE 24.—*Selected reservoir sites in the Alabama River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Etowah River, Dawson County, Ga.	270	2.54	690	6,020	80	100	4,200
Etowah River, east of Cartersville, Ga.	920	2.54	2,300	63,560	800	180	24,000
Oostanaula River, near Rome, Ga.	1,670	2.25	3,800	3,200	40	40	5,640
Pinelog Creek, northeast of Rome, Ga.	110	2.25	250	2,000	30	50	2,840
Coosawattee River, Gordon County, Ga.	531	2.34	1,200	2,200	30	30	5,040
Conasauga River, east of Dalton, Ga.	470	2.25	1,000	18,400	250	50	25,600
Conasauga River, above last section	150	2.25	340	7,700	110	50	10,720
Coosa River, above Gadsden, Ala.	5,540	1.76	10,560	9,800	130	45	15,200

The indicated horsepower developed by the Coosa River along various sections from Wetumpka to Rome is set forth in Table 25.

TABLE 25.—*Indicated horsepower developed by Coosa River between Wetumpka and Rome.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Coosa River:	*Miles.*	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
From Wetumpka to Town Creek.	16	10,000	4,000	6,800	78	28,400	48,300	28,000	56,000	112,000
From Town Creek to Hatchet Creek.	14	9,500	3,800	6,460	36	12,400	21,200	12,800	25,600	51,200
From Hatchet Creek to Waxahatchee Creek.	15	9,000	3,600	6,120	89	29,200	49,600	31,700	63,400	126,800
From Waxahatchee Creek to Beeswax Creek	15	8,500	3,400	5,780	30	9,180	15,600	10,600	21,200	42,400
From Beeswax Creek to Tallasseehatchee Creek	16	8,000	3,200	5,440	8	2,360	4,000	2,900	5,800	11,600
From Tallasseehatchee Creek to Choccolocco Creek	30	7,500	3,000	5,100	42	11,500	19,600	15,000	30,000	60,000
From Choccolocco Creek to below Lock No. 3	32	7,000	2,800	4,760	26	6,640	11,250	9,300	18,600	37,200
From foot of Lock No. 3 to head of Lock No. 1	5	6,500	2,600	4,420	21	4,900	8,320	7,400	14,800	29,600
Total						104,580	177,870	117,700	235,400	470,800

From Wetumpka up to Greensport, a distance of about 140 miles, the slope is comparatively steep. Plans for the canalization of this river for navigation involve the construction of a series of 31 locks and dams, which would practically utilize all the fall between the two points. Thus, the statement of indicated horsepower approximates that which could be economically developed in practice. Above Lock No. 1 at Greensport the river extends 130 miles to Rome, but the fall is only 55 feet and no waterpower is available.

The Oostanaula River, the northern affluent of the Coosa, is formed at Resaca by the junction of the Coosawattee and the Connasauga. This point is 43 miles above Rome. Along this stretch there is a total fall of 50 feet, which is a little more than 1 foot per mile, and, therefore, the country is not well adapted for the development of power. The Coosawattee, from its mouth 22 miles up to Talking Rock, has a fall of 62 feet. The drainage area for the section is 680 square miles and the minimum discharge 476 cubic feet per second, which will provide a minimum indicated horsepower of 2,410. From Talking Rock up to the head of the river at Ellijay, a distance of 23 miles, there is a total fall of 582 feet. The mean drainage area for the section is 300 square miles and the minimum flow is 345 cubic feet per second, which will provide a minimum indicated horsepower of 16,500. As the river along this section is a continuous shoal, the entire fall is available for development. Hence the figure given above can be easily realized in actual practice. Cartecay River, an important tributary of the Coosawattee, has a fall of 390 feet in the 15 miles from the mouth up to Pumpkin Creek. The mean discharge is 144 cubic feet per second; the minimum indicated horsepower produced is, therefore, 4,590, and the minimum for the 6 highest months is 6,880.

The Connasauga River, the other affluent of the Oostanaula, has a minimum indicated horsepower of 6,650, distributed along the 32 miles of the river from Beaverdale to the head and along the Jack River, a tributary of the Connasauga.

ETOWAH RIVER.

We come now to the Etowah River, the southern affluent of the Coosa. The horsepowers developed by various sections of the river are shown in Table 26.

TABLE 26.—*Indicated horsepower developed by Etowah River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Etowah River:										
From mouth to Euharlie Creek.	*Miles.* 31	*Sq. miles.* 1,720	*Sec. ft.* 912	*Sec. ft.* 1,370	*Feet.* 72	5,970	8,950	16,000	32,000	64,000
From Euharlie Creek to Cartersville.......	15	1,270	698	1,050	36	2,290	3,430	8,000	16,000	32,000
From Cartersville to Owl Creek..........	10	1,040	624	936	[a] 84	4,750	7,130	14,000	28,000	56,000
From Owl Creek to Little River.	7	935	608	912	17	945	1,420	Submerged.		
From Little River to Amicalola River...	36	490	441	662	[b] 225	9,000	13,500	1,800	3,600	7,200
From Amicalola River to Nimblewill Creek...	20	110	110	165	315	3,150	4,720	None.	None.	None.
From Nimblewill Creek to Jones Creek..........	1	43	47	70	27	115	173	None.	None.	None
From Jones Creek to head..	7	[c] 23	25	38	[d] 210	477	716	None.	None.	None.
Total.......	......	....	....	....	......	266,970	40,039	39,800	79,600	159,200

[a] Reduced to 70 feet by proposed Cartersville reservoir.
[b] Reduced to 105 feet by proposed Dawson reservoir.
[c] Total area.
[d] Mean head.

OHIO RIVER TRIBUTARIES.

The tributaries of the Ohio River considered in this discussion are the Monongahela, Great Kanawha, and Tennessee. Two other great streams have their headwaters in the Southern Appalachians, the Kentucky and Cumberland Rivers, but they are not considered in this paper, because the surveys available in their drainage areas cover so small an area that a comprehensive statement concerning the power developed on each can not be made at this time.

MONONGAHELA RIVER.

Monongahela River joins with the Allegheny at Pittsburg to form the Ohio. The drainage area, 7,350 square miles in extent, lies within the States of Pennsylvania, West Virginia, and Maryland. A short distance above the confluence of the Monongahela with the Allegheny, the Youghiogheny enters. This stream has a drainage area of 1,750 square miles.

Monongahela River has been extensively canalized for navigation, there being 15 locks and dams between the mouth and Fairmont, W. Va. The effect of these dams, so far as power is concerned, is to concentrate the natural fall of the river at 15 points, which would provide excellent water-power facilities, if the amount of summer flow were sufficient to make development worth while. Therefore, it will be seen that the preservation of summer flow, through the forestation of the uplands and the installation of reservoirs, is one of the directly important features of improvement in these drainage areas. From among the many reservoir sites that appear upon a survey of the basin, those shown in Table 27 have been selected as producing the best combination for all purposes.

TABLE 27.—*Selected reservoir sites in the Monongahela River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Dunkard Creek, Cass County, W. Va.	160	1.7	270	8,300	150	100	5,800
Buffalo Creek, Mannington, W. Va.	40	1.7	70	2,400	40	59	2,100
Booths Creek, Monongah, W. Va.	40	1.7	70	2,800	40	101	1,600
Sandy Creek, Grafton, W. Va.	80	1.7	140	6,200	80	155	3,600
Teter Creek, Nestorville, W. Va.	40	1.7	60	2,600	40	115	1,300
Elk Creek, Clarksburg, W. Va.	100	1.7	170	5,900	100	92	4,500
West Fork River, Clarksburg, W. Va.	380	1.7	640	24,700	380	109	15,900
Buckhannon River, Buckhannon, W. Va.	310	1.7	530	18,800	310	77	13,300
Middle Fork Tygart, Barbour County, W. Va.	140	1.7	230	8,100	140	107	4,300
Cheat River, Tucker County, W. Va.	820	1.7	1,400	23,800	440	200	6,600
Tygart River, Beverly, W. Va.	330	1.7	560	19,100	330	142	10,000

Monongahela River is formed a short distance above Fairmont, W. Va., by the junction of Tygarts Valley River and West Fork. The indicated horsepower developed by the main stem is set forth in Table 28.

TABLE 28.—*Indicated horsepower developed by Monongahela River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Monongahela River:										
From lower level Dam No. 1 to upper level Dam No. 4	*Miles* 39.2	*Sq. miles.* 6,280	*Sec. ft.* 879	*Sec. ft.* 3,450	*Feet.* 28.8	2,300	9,030	9,080	18,200	36,400
From lower level Dam No. 5 to upper level Dam No. 6	9.8	4,790	671	2,640	23.0	1,400	5,520	7,250	14,500	29,000
From lower level Dam No. 7 to upper level Dam No. 9	10.6	3,600	504	1,980	29.7	1,360	5,340	8,120	16,200	32,400
From lower level Dam No. 10 to upper level Dam No. 15	21.4	2,510	351	1,350	57.6	1,840	7,070	13,000	26,000	52,000
Total						6,900	26,960	37,450	74,900	149,800

In connection with Table 28, special consideration should be given to the amount of power available from storage. Here is a river canalized by the Government at an expense of over $6,000,000, and which might be made to produce enormously profitable return on this investment if the work were completed by the reservation and forestation of the uplands and by the establishment of the necessary reservoir system. On the basis of a distribution of the stored waters over the entire year the income from water-power rental at an average of $20 per horsepower per year would be $885,000, or equivalent to a 3 per cent income on an investment of $29,500,000.

TYGARTS VALLEY RIVER.

This affluent of the Monongahela River is 121 miles long from source to mouth, and has a total drainage area of 1,420 square miles. The indicated horsepower developed along the river is set forth in Table 29.

TABLE 29.—*Indicated horsepower developed by Tygarts Valley River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Tygarts Valley River:										
From above West Fork River to below junction Frog Run	*Miles.* 28	*Sq. miles.* 1,320	*Sec. ft.* 251	*Sec. ft.* 990	*Feet.* 121	2,760	10,900	16,700	33,400	66,800
From below junction Frog Run to below Buckhannon River	23	1,080	238	918	288	6,230	24,000	35,700	71,400	142,800
From above Buckhannon River to below junction of Middle Fork	3.5	596	143	666	139	1,810	7,150	10,000	20,000	40,000
From above junction Middle Fork to above Roaring Creek	16.5	379	95	375	225	1,940	7,670	11,500	23,000	46,000
From 2 miles above Roaring Creek to below Pound Mill Run	31	205	51	203	252	1,170	4,650	Partly submerged.		
From below Pound Mill Run to source	19	[a] 88	22	87	[b] 1,800	900	3,560	None.	None.	None.
Total	......	....	....	....	......	14,810	57,930	73,900	147,800	295,600

[a] Total area.

[b] 25 per cent total fall.

WEST FORK.

West Fork, which joins with the Tygarts Valley River to form the Monongahela, is not well adapted for the development of extensive power. Along the first 70 miles of its course, from the mouth to Washburn Run, the fall is only 160 feet. In the next 22 miles, to the head of the river, the fall is 500 feet, but the drainage area is small.

OTHER TRIBUTARIES OF MONONGAHELA RIVER.

Cheat River.—Cheat River is an important tributary, entering the Monongahela from the east some distance below Morgantown, W. Va. The indicated horsepower developed at selected sections along the stream is set forth in Table 30.

TABLE 30.—*Indicated horsepower developed by Cheat River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Cheat River:										
From mouth to Albright	*Miles* 29	*Sq. miles.* 1,220	*Sec. ft.* 171	*Sec. ft.* 720	*Feet.* 360	5,600	23,600	24,200	48,400	96,800
From above Albright to below junction Dry Fork	45	865	121	510	[a] 397	4,360	18,400	18,800	37,600	75,200
From above junction Dry Fork to 3,000-foot contour	45	151	21	89	1,230	2,350	9,950	Partly submerged.		
From 3,000-foot contour to source	30	[b] 88	12	52	[c] 375	410	1,780	None.	None.	None.
Total						12,720	53,730	43,000	86,000	172,000

[a] Fall reduced to 280 feet by proposed Cheat reservoir. [b] Total area. [c] 25 per cent total fall.

Buckhannon River.—This river is 61 miles long and its basin is 350 square miles in extent. The first section of 11 miles above the mouth has a total fall of 60 feet. The minimum flow in cubic feet per second is 66, while the minimum for the 6 highest months is 261. This will produce a minimum indicated horsepower of 324 and a minimum for the 6 highest months of 1,280 horsepower. Along the next 33 miles of the course, from Sand Run to Alexander, the total fall is 470 feet, and the minimum flow 40 cubic feet per second, which will produce a minimum indicated horsepower of 1,540. The minimum for the 6 highest months is 6,070. From Alexander to the source of the river, a distance of 17 miles, there is a fall of 1,300 feet, but the drainage area is only 90 square miles in extent, so the power available for development is inconsiderable.

Middle Fork.—Along the lower 25 miles of this fork there is a total fall of 540 feet and a mean drainage area of 113 square miles, producing a minimum flow of 25 cubic feet per second, or an indicated minimum horsepower of 1,100. The upper 15 miles of the river has a fall of 1,200 feet, but the drainage area is only 65 square miles in extent and the power actually available is limited.

Other tributaries of considerable importance as sources of power are Dry Fork, Laurel and Gladys forks, Black Water River, Dunkard and Sandy creeks.

Youghiogheny River.—This river enters the Monongahela at McKeesport, above which point it has a total drainage area of 1,750 square miles. Survey of reservoir sites has been made over only a part of its basin, but those identified are shown in Table 31.

TABLE 31.—*Selected reservoir sites in the Youghiogheny River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Youghiogheny River, Friendsville, Md	270	2.47	690	20,270	255	240	4,220
Deep Creek, Garrett County, Md	55	2.47	136	4,603	58	83	3,200
Cherry Creek, Garrett County, Md	55	2.47	136	4,912	62	64	3,930
Muddy Creek, Garrett County, Md	13	2.47	32	1,065	13	70	1,100
Harrington Creek, Garrett County, Md	13	2.47	32	900	11	60	760

It is probable that, were surveys available on the remainder of the drainage area, it would be found that the storage capacity on the upper Youghiogheny would be from two and one-half to three times that expressed in the above table. The indicated horsepower along the river from McKeesport to the source, not including Laurel Hill and Castleman rivers, is set forth in Table 32.

TABLE 32.—*Indicated horsepower developed by Youghiogheny River between McKeesport and the source.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 monhts.
Youghiogheny River:										
From McKeesport to West Newton	*Miles.* 19	*Sq. miles.* 1,650	*Sec. ft.* 297	*Sec. ft.* 1,170	*Feet.* 27	730	2,870	2,360	4,720	9,440
From West Newton to Connellsville	26.5	1,400	252	990	111	2,540	10,000	9,700	19,400	38,800
From Connellsville to Confluence	17.5	1,120	202	795	408	7,500	29,400	35,700	71,400	142,800
From Confluence to Friendsville	15	365	80	288	[a] 122	890	3,190	2,800	5,600	11,200
From Friendsville to Little Youghiogheny River	26	204	45	161	810	3,320	11,900	18,000	36,000	72,000
From below junction Little Youghiogheny River to source	37	[b] 112	25	88	[c] 87.5	200	700	370	740	1,480
Total						15,180	58,000	68,930	137,860	275,720

[a] Fall reduced to 32 feet by proposed Youghiogheny reservoir.
[b] Total area.
[c] 25 per cent total fall. Fall reduced 64 feet by proposed Cherry Creek reservoir.

GREAT KANAWHA RIVER.

The main stem of Great Kanawha River extends from the Ohio River 98 miles to the junction of Gauley River. Above this point the river is known as New River, extending 255 miles to the junction of North and South forks. The lower 96 miles of Kanawha River is canalized to insure a minimum depth of 6 feet for navigable purposes. For the first 79 miles, or up to the confluence of Paint Creek, canalization is accomplished by movable dams, 8 in number, and for the remainder of the distance by fixed dams, 2 in number. The presence of these movable dams forbids the installation of power systems along that portion of the river, and since the very object of installing movable dams is to provide for open navigation, this, of course, would be defeated by the introduction of fixed dams. This part of the river may, therefore, be disregarded so far as power development is concerned, although the minimum indicated horsepower along this portion of the stream, as shown by its minimum flow and its natural slope, is nearly 20,000. The slope is exceedingly gradual, however, and it is doubtful if any considerable part of this power could be developed without unreasonable expenditure, even if the present system of movable dams had not been installed. In fact, it is clear that the river along this part is far more important as a waterway than as a source of power. The indicated horsepower from the foot of Loup Creek Shoal up to the confluence of North and South forks of New River is set forth in Table 33.

TRIBUTARIES OF GREAT KANAWHA RIVER.

SOUTH FORK OF NEW RIVER.

South Fork of New River is 78 miles long and in the lower 55 miles of its course has a total fall of 500 feet. The mean drainage area for the section is 207 square miles and the minimum discharge 145 cubic feet per second, which will produce a minimum indicated horsepower of 5,930, or a minimum for the 6 highest months of 10,200.

NORTH FORK OF NEW RIVER.

North Fork of New River is 42 miles long, and along the lower 28 miles of its course there is a total fall of 390 feet. The mean drainage area is 170 square miles, which produces a minimum flow of 85 cubic feet per second. This will provide for a minimum indicated horsepower of 2,710, or a minimum for the 6 highest months of 5,420.

TABLE 33.—*Indicated horsepower developed by Great Kanawha River between Pool No. 2 and confluence of North and South forks.*

Section of river	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
	Miles.	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
Great Kanawha River, from foot of Loup Creek Shoal to below junction Gauley River	9	8,310	2,240	5,810	46	9,370	24,300	27,700	55,400	110,800
New River:										
From above junction Gauley River to 1,000-foot contour	19	6,780	1,830	4,740	316	52,500	136,000	148,000	296,000	592,000
From 1,000-foot contour to 1,200-foot contour	24	6,560	1,770	4,590	180	29,000	75,200	84,400	168,800	337,600
From 1,200-foot contour to below junction Greenbrier River	20	6,300	1,700	4,410	164	25,400	65,700	76,800	153,600	307,200
From above junction Greenbrier River to below junction Island Creek	20	4,220	1,400	3,550	69	8,780	22,300		Submerged.	
From above junction Island Creek to below junction Wolf Creek	17	3,750	1,280	3,220	[a] 66	7,680	19,300	7,300	14,600	29,200
From above junction Wolf Creek to below junction Sinking Creek	19	3,240	1,140	2,850	85	8,800	22,000	23,300	46,600	93,200
From above junction Sinking Creek to head Siffords Falls	8	2,920	1,050	2,600	50	4,780	11,800	13,100	26,200	52,400
From head Siffords Falls to Godbys Ferry	32	2,660	985	2,420	[b] 71	6,360	15,600	11,000	22,000	44,000
From Godbys Ferry to Ashworth	13	2,320	880	2,160	76	6,080	14,900		Submerged.	
From Ashworth to below junction Reed Creek	9	2,020	810	1,900	28	2,060	4,840	2,400	4,800	9,600
From above junction Reed Creek to Union Lead Mines	10	1,450	623	1,400	61	3,450	7,760	3,820	7,640	15,300
From Union Lead mines to 2,200-foot contour	16	1,240	571	1,220	[c] 230	11,900	25,500	3,270	6,540	13,100
From 2,200-foot contour to below junction North Fork	48	875	472	875	270	11,600	21,500	None.	None.	None.
Total						187,760	466,700	401,090	802,180	1,604,400

[a] Fall reduced to 26 feet by proposed lower New River reservoir.
[b] Fall reduced to 42 feet by proposed Radford reservoir.
[c] Fall reduced to 60 feet by proposed Carroll reservoir.

GREENBRIER RIVER.

Greenbrier River has a total drainage area of 1,580 square miles and a length from source to mouth of 151 miles. The reservoir sites on this river propose the conservation of the entire discharge from 1,000 square miles. Therefore, the power available for development with storage reservoirs established will be considerably different from that under the present conditions. The following statement of indicated horsepower along various sections of the river is, therefore, given, without reference to storage possibilities except that in the last three columns there is a statement of the amount of power that would be derived from storage along the sections not submerged by the proposed reservoirs.

TABLE 34.—*Indicated horsepower developed by Greenbrier River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Greenbrier River:										
From mouth to below Second Creek	*Miles.* 36	*Sq. miles.* 1,460	*Sec. ft.* 161	*Sec. ft.* 481	*Feet.* 234	3,420	10,200	30,600	61,200	122,400
From above Second Creek to below Anthony Creek	23	1,100	121	363	[a] 198	2,180	6,530	19,000	38,000	76,000
From above Anthony Creek to below Knapp Creek	40	670	74	221	[a] 270	1,820	5,430	6,060	12,120	24,240
From above Knapp Creek to below North Fork	21	326	36	108	[b] 279	910	2,740	6,700	13,400	26,800
From above North Fork to below East Fork	13	148	16	49	234	340	1,040	None.	None.	None.
From below junction East Fork to source	18	[c] 130	14	43	[d] 250	318	980	None.	None.	None.
Total						8,988	26,920	62,360	124,720	249,440

[a] Fall reduced to 145 feet by proposed Lewisburg reservoir.
[b] Fall reduced to 160 feet by proposed Pocahontas reservoir.
[c] Total area.
[d] 25 per cent total fall.

GAULEY RIVER.

Gauley River has a total drainage area of 1,430 square miles and from source to mouth is 108 miles long. The conditions with reference to storage and its effects on available power are similar to those already described for Greenbrier River. Table 35 shows indicated horsepower along chosen sections, together with a statement of the power available from storage along those sections not submerged by the proposed reservoirs.

TABLE 35.—*Indicated horsepower developed by Gauley River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	8 months.
Gauley River:										
From mouth to below junction Meadow River.	*Miles* 27	*Sq. miles.* 1,310	*Sec. ft.* 354	*Sec. ft.* 917	*Feet.* [a] 432	13,900	36,000	9,270	18,500	37,000
From above Meadow River to below junction Cranberry River....	31	573	155	400	693	9,760	25,200	3,310	6,630	13,260
From above junction Cranberry River to below junction Williams River	17	209	56	146	252	1,280	3,350	None.	None.	None.
From below junction Williams River to source.........	33	[b] 181	49	127	[c] 500	2,230	5,770	None.	None.	None.
Total........	......	....	....	......	....	27,170	70,320	12,580	25,130	50,260

[a] Fall reduced to 300 feet by proposed Gauley reservoir. [b] Total area. [c] 25 per cent total fall.

Tributaries of Gauley River.—Indicated horsepower on tributaries of Gauley River is given in Table 36.

TABLE 36.—*Indicated horsepower developed by tributaries of Gauley River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Meadow River:										
From mouth to 1,800-foot contour...........	*Miles.* 8	*Sq. miles.* 350	*Sec. ft.* 95	*Sec. ft.* 245	*Feet.* 603	5,200	13,400	13,700	27,400	54,800
From 1,800-foot contour to 2,200-foot contour...........	11	295	80	206	360	2,620	6,740	8,200	16,400	32,800
From 2,200-foot contour to below Big Clear Creek....	18	222	60	155	270	1,470	3,800	5,700	11,400	22,800
From below Big Clear Creek to source.........	19	[a] 165	45	115	[b] 350	1,430	3,660	Submerged.		
Hominy Creek, from mouth to source...........	18	[a] 98	26	69	[b] 375	890	2,350	None.	None.	None.
Muddlety Creek, from mouth to source...........	22	[a] 66	18	46	[b] 250	409	1,050	Submerged.		
Cherry Creek, from mouth to source.	25	[a] 168	45	118	[b] 500	2,050	5,360	None.	None.	None.
Cranberry River, from mouth to source...........	30	[a] 102	28	71	[b] 525	1,340	3,390	None.	None.	None.
Twenty-mile Creek from mouth to source...........	30	[a] 75	20	52	[c] 350	636	1,650	....	....	....
Total........	......	....	....	......	......	16,045	41,400	27,600	55,200	110,400

[a] Total area. [b] 25 per cent total fall. [c] Fall reduced 220 feet at mouth by proposed Gauley reservoir.

ELK RIVER.

Elk River, which enters the Kanawha at Charleston, is 171 miles long and has a total drainage area of 1,550 square miles. Of this area, the proposed reservoir in Clay County would conserve all the flow from 940 square miles. Therefore, an estimate of power with the reservoir constructed would be totally different from the estimate under the present conditions, which are similar to those already described for Greenbrier River. The indicated horsepower on the main stream is set forth in Table 37.

TABLE 37.—*Indicated horsepower developed by Elk River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Elk River:										
From mouth to below junction Buffalo Creek..	*Miles* 51	*Sq. miles.* 1,280	*Sec. ft.* 346	*Sec. ft.* 895	*Feet.* 135	4,250	11,000	16,900	33,800	67,600
From above junction Buffalo Creek to below junction Birch Creek....	25	832	225	583	[a] 45	920	2,380	None.	None.	None.
From above junction Birch Creek to below junction Holly Creek.........	30	552	149	386	162	2,200	5,690	Submerged.		
From above junction Holly Creek to below junction Back Fork..........	25	282	76	197	505	3,490	9,040	None.	None.	None.
From below junction Back Fork to source.	40	[b] 227	61	159	[c] 625	3,470	9,040	None.	None.	None.
Total.......						14,330	37,150	16,900	33,800	67,600

[a] Fall reduced about 25 feet by proposed Elk River reservoir. [b] Total area. [c] 25 per cent total fall.

Tributaries of Elk River.—The principal tributaries of Elk River are Holly and Birch rivers and Buffalo Creek, which furnish minimum indicated horsepowers of 1,860, 1,730, and 990, respectively.

TENNESSEE RIVER.

The Tennessee is one of the most important rivers in the United States, both from the standpoint of navigation and of available water power. Its basin includes an enormous area in the Appalachian Mountains, and its value as a public resource is, therefore, markedly affected by the conditions prevailing in that region. The devastation of the protective forest cover in these mountains would not only reduce all the power and navigation values along the stream, but would also result in a denudation of alluvial lands now fertile and productive. The total loss to the valley could hardly be overestimated.

The lower section, between Riverton and the mouth, is not considered in this report. This portion is essentially a great commercial highway, and its very gradual slope renders it impossible to develop power to advantage. Above Riverton it has a total drainage area of 30,800 square miles, and a minimum discharge of 12,000 cubic feet per second.

Storage facilities in the basin are enormous. Table 38 contains the facts concerning certain chosen reservoir sites, which are of a sufficient capacity to conserve the annual run-off from an area of 12,800 square miles.

TABLE 38.—*Selected reservoir sites in the Tennessee River basin.*

Stream and location.	Catchment area.	Mean annual run-off per square mile.	Flow available.	Capacity of reservoir.	Capacity of reservoir in catchment area.	Height of dam.	Area of flow line.
	Square miles.	*Cu. feet per sec.*	*Cu. feet per sec.*	*1,000,000 cu. feet.*	*Square miles.*	*Feet.*	*Acres.*
Clinch River, Scott County, Va....	780	1.38	1,080	30,400	690	180	10,000
Nolichucky River, Greenville, Tenn.	940	1.69	1,590	14,700	270	100	10,200
Clinch River, Sneedville, Tenn.....	560	1.38	770	18,500	390	100	8,500
Powell River, Jonesville, Va.......	570	1.38	790	17,100	380	100	12,000
Holston River, northeast of Knoxville, Tenn..........................	3,400	1.56	5,300	163,500	3,300	160	49,000
French Broad River, east of Knoxville, Tenn..........................	4,050	1.56	6,300	199,600	4,000	200	70,000
Little River, south of Knoxville, Tenn.............................	290	1.56	450	17,400	290	94	12,100
Little Tennessee River, Loudon County, Tenn....................	2,520	2.78	7,000	78,000	860	100	54,400
Little Tennessee River, Swain County, Tenn....................	380	2.78	1,050	7,340	80	100	5,120
Clinch River, Roane County, Tenn.	2,110	1.38	2,900	26,500	600	60	30,000
Cheoah River, Graham County, N. C..............................	180	2.78	500	6,700	75	150	2,840
Hiwassee River, Cherokee County, N. C..............................	550	2.63	1,450	32,400	380	200	11,060
Nottely River, Union County, Ga..	240	1.70	410	1,000	20	40	1,680
Toccoa River, Fannin County, Ga.	240	2.14	510	4,130	60	100	2,880
Hiwassee River, Hiwassee, Ga....	100	2.63	260	2,240	40	100	1,600
Tennessee River, Rabun County, Ga...............................	50	4.35	220	2,720	20	50	3,800
Hiwassee River, near mouth, Tenn.	2,040	2.12	4,300	77,500	1,130	70	70,000
West Chickamauga Creek, Walker County, Ga.....................	80	2.00	160	5,260	80	60	6,300
South Chickamauga Creek, Catoosa County, Ga...............	110	2.00	220	6,330	100	60	7,400
Sequatchie River, Sequatchie County, Tenn....................	330	2.00	660	4,000	60	50	5,500

It is doubtful whether it would be wise to install the whole of the great conservation system indicated in the above table. There has been no opportunity for a critical study of this subject, and the facts given merely show the possibilities for storage.

Considering the main stream from Riverton to the mouth of Holston River, there are two sections along which a great horsepower is indicated. The first section from Riverton to the head of Elk Shoals is 60 miles long and has a total fall of 165 feet. The minimum indicated horsepower thereby produced is 162,000 and the minimum for the 6 highest months would be 275,000. The increase from storage, considering full reservoirs, would be as follows:

Distributed over 1 year	396,000
Distributed over 6 months............................	792,000
Distributed over 3 months............................	1,584,000

The next section extends from The Pan to Chattanooga, a distance of 20 miles, with a total fall of 28 feet. The minimum discharge along this section is 10,000 cubic feet per second, giving a minimum indicated horsepower of 22,900, or a minimum for the 6 highest months of 38,900. This would be increased by storage, considering full reservoirs, as follows:

Distributed over 1 year	67,000
Distributed over 6 months	134,000
Distributed over 3 months	268,000

A short distance above Knoxville, Tenn., the Hiwassee and French Broad rivers join to form the Tennessee.

HIWASSEE RIVER.

From the mouth of the Hiwassee to Ocoee River, a distance of 35 miles, the fall is only 33 feet; therefore, this stretch is not available for the practical development of power. The indicated horsepower for the remainder of the stream is set forth in Table 39.

TABLE 39.—*Indicated horsepower developed by Hiwassee River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Hiwassee River:										
From Ocoee River to Savannah Ferry	*Miles* 9	*Sq. miles.* 1,310	*Sec. ft* 972	*Sec. ft.* 1,560	*Feet.* 20	1,750	2,790	Submerged.		
From Savannah Ferry to Reliance	6	1,220	915	1,460	36	3,000	4,800	3,500	7,000	14,000
From Reliance to Coco Creek	9	1,150	874	1,400	153	12,200	19,400	17,000	34,000	68,000
From Coco Creek to Turtletown Creek	3	1,060	806	1,290	[a]231	15,200	24,300	23,100	46,200	92,400
From Turtletown Creek to Apalachia, Tenn	3									
From Apalachia, Tenn., to Apalachia, N. C.	2									
From Apalachia, N. C., to Beaverdam Creek	14	1,000	780	1,250	131	9,270	14,800	Submerged.		
From Beaverdam Creek to Nottely River	15	910	710	1,140	136	8,780	14,000	Submerged.		
From Nottely River to Valley River	5	560	437	699	46	1,830	2,920	Submerged.		
From Valley River to Brasstown Creek	7	390	320	512	63	1,840	2,930	445	890	1,780
From Brasstown Creek to Shooting Creek	18	240	240	384	205	4,470	7,160	1,450	2,900	5,800
From Shooting Creek to Hightower Creek	10	110	121	194	117	1,290	2,060	670	1,340	2,680
Total						59,630	95,160	46,165	92,330	184,660

[a] Mean head.

Tributaries of Hiwassee River.—The principal tributary of the Hiwassee is the Ocoee, which has a total drainage area of 635 square miles. Along the upper 57 miles of its course the name Toccoa is given to the river. The indicated horsepower along the entire section is set forth in Table 40.

TABLE 40.—*Indicated horsepower developed by Ocoee-Toccoa River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Ocoee River:										
From mouth to Sylco Creek....	*Miles.* 16	*Sq. miles.* 600	*Sec. ft.* 600	*Sec. ft.* 960	*Feet.* 70	3,830	6,140	567	1,134	2,268
From Sylco Creek to Big Creek..........	3	550	578	925	57	2,980	4,770	745	1,490	2,980
From Big Creek to Bush Creek.	13	500	550	880	522	26,100	41,800	6,850	13,700	27,400
From Bush Creek to Fightingtown Creek....	5	440	506	810	34	1,580	2,520	Limited amount.		
Toccoa River:										
From above Fightingtown Creek to Blue Ridge Station, Morganton Bridge.........	15	300	390	624	92	3,260	5,210	1,210	2,420	4,840
From Blue Ridge to Dial Station.	21	180	252	403	280	6,440	10,300	Fall reduced one-third by Toccoa reservoir.		
From Dial Station to Coopers Creek..........	7	100	145	232	153	2,020	3,220	None.	None.	None.
Total........	......	....	....	....	......	46,210	73,900	9,372	18,744	37,488

EXPLANATORY NOTE.—Mouth of Ocoee to Sylco Creek—fall reduced 30 feet by proposed Hiwassee reservoir.

The remaining tributaries of Hiwassee River afford good power sites for limited development, but the drainage areas are, in the main, so small that they will not be considered in this report except in the case of Nottely River, which enters the Hiwassee near Murphy, Tenn. The Nottely develops an indicated horsepower as follows: From the mouth to Ranger, a distance of 9 miles, there is a total fall of 85 feet and a minimum discharge of 224 cubic feet per second, which will provide for a minimum indicated horsepower of 1,560. The minimum for the 6 highest months is 2,490. From Ranger to Young Cane Creek, a distance of 20 miles, there is a fall of 155 feet and a minimum flow of 187 cubic feet per second, which will provide for a minimum indicated horsepower of 2,380. The minimum for the 6 highest months is 3,800. This power would be obliterated by the Nottely reservoir.

CLINCH RIVER.

The tributary of the Tennessee River of next importance is Clinch River, which has a drainage area of 4,390 square miles. The indicated horsepower along this stream is set forth in Table 41.

TABLE 41.—*Indicated horsepower developed by Clinch River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Clinch River:										
From Emory Creek to Clinton	*Miles.* 55	*Sq. miles.* 3,200	*Sec. ft.* 960	*Sec. ft.* 1,440	*Feet.* 68	5,895	8,840	Submerged.		
From Clinton to Powell River	31	2,840	852	1,280	50	3,834	5,740	10,300	20,600	41,200
From Powell River to near Sycamore Creek, Southern Railway bridge	48	1,740	522	783	133	6,318	9,450	20,600	41,200	82,400
From near Sycamore Creek, Southern Railway bridge, to North Clinch River	45	1,450	435	652	171	6,750	10,100	19,500	39,000	78,000
From North Clinch River to Clinchport station	20	1,070	321	482	54	1,575	2,360	Submerged.		
From Clinchport station to Indian Creek	110	550	165	248	680	10,125	15,210	8,600	17,200	34,400
Total						34,497	51,700	59,000	118,000	236,000

EXPLANATORY NOTES.—Fall between Southern Railway bridge and North Clinch River reduced to 140 feet by Sneedville reservoir. Fall between Clinchport and Indian Creek reduced to 100 feet by Clinch River reservoir.

Tributaries of Clinch River.—The most important tributary is Powell River, which has a total drainage area of 940 square miles. The amount of indicated horsepower along various sections of this river and designated tributaries is set forth in Table 42.

TABLE 42.—*Indicated horsepower developed by Powell River and tributaries.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of— 12 months.	6 months.	3 months.
Powell River:										
From mouth to North Powell..	*Miles.* 100	*Sq. miles.* 610	*Sec. ft.* 183	*Sec. ft.* 274	*Feet.* 387	6,440	9,630	9,640	19,280	38,560
From North Powell to South Powell..	17	170	51	76	198	918	1,380	None.	None.	None.
From South Powell to Callihan Creek....	4	101	30	45	54	144	216	None.	None.	None.
North Fork, Powell River, from mouth to head..	17	[a] 91	27	40	[b] 330	810	1,220	None.	None.	None.
South Fork, Powell River, from mouth to head..	12	[a] 37	11	16	[b] 730	730	1,100	None.	None.	None.
Copper Creek, from mouth to head..	41	[a] 136	41	62	[b] 336	1,250	1,880	None.	None.	None.
Guest River, from mouth to head..	19	[a] 96	29	44	[b] 480	1,270	1,900	None.	None.	None.
Maiden Spring Creek, from mouth to head..	35	[a] 119	36	54	[b] 430	1,400	2,100	None.	None.	None.
Total........	......	....	....	....	......	12,962	19,426	9,640	19,280	38,560

[a] Total area. [b] Mean head.

EXPLANATORY NOTE.—Water fall between mouth and North Powell reduced to 200 feet by Jonesville reservoir.

LITTLE TENNESSEE RIVER.

Above the Hiwassee and Clinch, on the Tennessee River, is the Little Tennessee, a stream having a total drainage area of 2,650 square miles. The indicated horsepower developed along various sections of this stream is set forth in Table 43.

TRIBUTARIES OF LITTLE TENNESSEE RIVER.

Some of the tributaries of Little Tennessee River are quite as important, from the standpoint of power development, as the main stream itself.

Tellico River is a stream having a total drainage area of 284 square miles. From the mouth to Tellico Plains, a distance of 22 miles, there is a fall of 120 feet, which, with a minimum discharge of 125 cubic feet per second, will furnish a minimum indicated horsepower of 1,224. The minimum for the 6 highest months will be 1,960. This part of the river would be submerged by the proposed Loudon

TABLE 43.—*Indicated horsepower developed by Little Tennessee River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Little Tennessee River:	*Miles.*	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
From mouth to below Tellico River, McGhee Station	20	2,560	2,050	3,280	27	5,030	8,050	6,370	12,740	25,480
From above Tellico, McGhee, to Abrams Creek	19	2,100	1,780	2,850	63	10,200	16,300	Submerged.		
From Abrams Creek to Tuckaseegee River	38	1,670	1,500	2,400	567	77,300	123,000	21,000	42,000	84,000
From Tuckaseegee River to Nantahala River	7	657	650	1,040	90	5,320	8,510	2,820	5,640	11,280
From Nantahala River to below Cullasaja River, Franklin	28	380	418	669	387	14,700	23,500	7,050	14,100	28,200
Total						112,550	179,360	37,240	74,480	148,960

EXPLANATORY NOTES.—Fall between mouth and McGhee reduced to 24 feet by Loudon reservoir. Fail between Nantahala and Cullasaja reduced to 250 feet by Swain reservoir.

reservoir. From Tellico Plains to the head of the river is a distance of 18 miles, with a total fall of 1,600 feet. Considering 700 feet of this as a mean working head, with a discharge of 102 cubic feet per second, the total minimum indicated horsepower is 6,490, and the minimum for the 6 highest months will be 10,400.

Citico Creek, a tributary 17 miles long, has a total mean head of 470 feet. The minimum discharge is 58 cubic feet per second, which will provide for a minimum indicated horsepower of 2,480. The available fall would be reduced 40 per cent by the proposed Loudon reservoir.

Abrams Creek, 15 miles long with a drainage area of 94 square miles, has a total fall of 1,110 feet. Considering 580 feet of this as a reasonable mean head, with a minimum discharge of 75 cubic feet per second, there will be developed a total minimum indicated horsepower of 3,950. The minimum for the 6 highest months will be 6,320 horsepower.

Cheoah Creek.—This is another important tributary of Little Tennessee River, with a total drainage area of 212 square miles. From the mouth to Snow Bird Creek, a distance of 13 miles, there is a total fall of 800 feet, with a minimum run-off of 130 cubic feet per second, which will produce a minimum indicated horsepower of 8,500. The minimum for the 6 highest months will be 13,600. On the same river from Snow Bird Creek to Tallula Creek, a distance of 4 miles, there is a total fall of 110 feet, which will produce a minimum horsepower of 396, with a discharge of 44 cubic feet per second. This power would be reduced approximately 50 per cent by the Cheoah reservoir. There are several tributaries of Cheoah Creek, such as Santeetla, Snow Bird, and Tallula creeks, which furnish fairly good sites for limited installation.

Tuckaseegee River.—The most important tributary of Little Tennessee River is the Tuckaseegee, which has a drainage area of 752 square miles. The indicated horsepower along certain sections of this river is shown in Table 44.

TABLE 44.—*Indicated horsepower developed by Tuckaseegee River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Tuckaseegee River:										
From Bryson City to Oconalufty River....	*Miles.* 6	*Sq. miles.* 635	*Sec. ft.* 540	*Sec. ft.* 864	*Feet.* 63	3,100	4,950			
From Oconalufty River to Scott Creek..........	16	375	319	510	144	4,180	6,680			
From Scott Creek to East Laport Station.	10	245	208	332	108	2,040	3,270			
From East Laport Station to West Fork....	6	174	157	251	63	900	1,440			
Total.......						10,220	16,340			

The Tuckaseegee itself has important tributaries, the most noticeable of which is the Oconalufty, which has a drainage area of 201 square miles. In the lower 5 miles of this stream there is an approximate fall of 150 feet, with a minimum discharge of 156 cubic feet per second, which will produce a minimum indicated horsepower of 1,920. The minimum for the 6 highest months will be 3,060 horsepower.

Nantahala River.—This river is 43 miles long and has a total drainage area of 180 square miles. Along the first 12 miles there is a total fall of 500 feet and a minimum run-off of 176 cubic feet per second, indicating a minimum horsepower of 7,200. The minimum for the 6 highest months would be 11,500. In the next 18 miles of the river there is a fall of 1,100 feet, about 80 per cent of which could be utilized. The minimum flow is 120 cubic feet per second, which would produce a minimum indicated horsepower of 10,800, and the minimum for the 6 highest months would be 17,300 horsepower. There are many other tributaries of the Little Tennessee providing good power sites for limited installation, but they will not be discussed in this paper.

FRENCH BROAD RIVER.

The main stem of the Tennessee is formed a short distance above Knoxville by the junction of the French Broad and Holston rivers. The former has a total drainage area of 4,810 square miles. The indicated horsepower along chosen sections of the French Broad River is set forth in Table 45.

TABLE 45.—*Indicated horsepower developed by French Broad River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
French Broad River:										
From mouth to Nolichucky River	*Miles.* 64	*Sq. miles.* 4,430	*Sec. ft.* 2,440	*Sec. ft.* 3,900	*Feet.* 135	30,000	48,000	Submerged.		
From Nolichucky River to Pigeon River	4	2,260	1,360	2,180	4.5	555	888	None.	None.	None.
From Pigeon River to Swannanoa River	64	1,750	1,220	1,950	828	91,800	147,000	None.	None.	None.
From Swannanoa River to East Fork	33	440	440	704	180	7,200	11,500	None.	None.	None.
From East Fork to West Fork	2	66	99	158	9	81	130	None.	None.	None.
From West Fork to head	12	[a] 36	54	86	[b] 710	3,480	5,570	None.	None.	None.
Total						133,116	213,088			

[a] Total area.

[b] Mean head.

TRIBUTARIES OF FRENCH BROAD RIVER.

Little Pigeon River.—This river is 30 miles long and has a total drainage area of 373 square miles. In the first 5 miles of the river, there is a fall of 50 feet, which, with the minimum discharge of 213 cubic feet per second, will give an indicated minimum horsepower of 871. This part of the course would be submerged by the proposed French

Broad reservoir. In the 25 miles above this first section, there is a total fall of 1,900 feet. Considering 480 feet of this as a reasonable working head, and a minimum discharge of 136 cubic feet per second, there is an indicated horsepower of 5,930. West Fork of Little Pigeon River has a drainage area of 142 square miles and a total fall of 1,500 feet in 21 miles. Considering 380 feet as the available working head, and 99 cubic feet per second as the minimum discharge, there is a minimum indicated horsepower of 3,420.

Nolichucky River is an important tributary of French Broad River having a drainage area of 1,760 square miles. The indicated horsepower along this river and tributaries is given in Table 46.

TABLE 46.—*Indicated horsepower developed by Nolichucky River and tributaries.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Nolichucky River:										
From mouth to Greeneville Station	*Miles.* 48	*Sq. miles.* 1,450	*Sec. ft.* 768	*Sec. ft.* 1,230	*Feet.* 180	12,600	20,200	8,360	16,720	33,440
From Greeneville Station to Toe River, Cane Creek	48	880	484	774	[a] 684	30,100	48,100	6,280	12,560	25,120
Toe River, from mouth to North Toe River and South Toe River	19	360	216	346	277	5,440	8,710	....	....	....
North Toe River, from mouth to head	41	[b] 198	113	181	[c] 510	5,240	8,380	....	....	....
Lick Creek, from mouth to head	30	[b] 262	157	251	[c] 70	1,000	1,600	....	....	....
Cane River, from mouth to Hinton Creek	15	124	87	139	387	3,060	4,900	....	....	....
Cane River, from Hinton Creek to head	20	[b] 64	45	72	[c] 550	2,250	3,600	....	....	....
North Indian Creek, from mouth to head	14	[b] 70	42	67	[c] 360	1,375	2,200	....	....	....
Total	......	....	....	....	......	61,065	97,690	14,640	29,280	58,560

[a] Fall reduced to 150 feet by proposed reservoir. [b] Total area. [c] Mean head.

Pigeon River.—This river is another important tributary of the French Broad, having a total drainage area of 667 square miles. The indicated horsepower along chosen sections of this stream and tributaries is set forth in Table 47.

TABLE 47.—*Indicated horsepower developed by Pigeon River and tributaries.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Pigeon River:										
From mouth to Cataluchee Creek	*Miles* 35	*Sq. miles.* 560	*Sec. ft.* 308	*Sec. ft.* 493	*Feet.* 504	14,100	22,600	....	....	....
From Cataluchee Creek to Richland Creek	15	312	187	299	720	12,200	19,600	....	....	....
From Richland Creek to West Fork	7	155	124	198	207	2,330	3,730	....	....	....
Cataluchee Creek, from mouth to head	10	[a] 62	43	69	[b] 700	2,740	4,380	....	....	....
Jonathan Creek, from mouth to head	16	[a] 65	46	74	[b] 700	2,930	4,690	....	....	....
West Fork, Pigeon River, from mouth to head	14	[a] 62	50	80	[b] 400	1,820	2,910	....	....	....
Total	......	....	....	....	......	36,120	57,910	....	....	....

[a] Total area. [b] Mean head.

The minimum indicated horsepower on other important tributaries of the French Broad is given in Table 48.

HOLSTON RIVER.

Holston River has a drainage area of 3,750 square miles, and is 142 miles long from its mouth up to the junction of North and South forks. In the lower 102 miles of the stream the fall is only 254 feet, or a little more than 2 feet per mile. In case the proposed Holston reservoir were constructed the fall would be reduced to 75 feet. The minimum indicated horsepower produced is 27,400. In the remaining 40 miles from Rogersville Station to the mouth of North and South forks there is a fall of 106 feet, and the minimum indicated horsepower here is 9,720, or 14,600 for the 6 highest months.

SOUTH FORK, HOLSTON RIVER.

South Fork is far more important a tributary than the North Fork, and has a total drainage area of 2,040 square miles. The indicated horsepower along several sections of this stream is set forth in Table 49.

TABLE 48.—*Indicated horsepower developed on other important tributaries of French Broad River.*

Section of river.	Length.	Total drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
	Miles.	*Sq. miles.*	*Sec. ft.*	*Sec. ft.*	*Feet.*					
Spring Creek, from mouth to head	16	72	43	69	[a] 730	2,850	4,560	....	....	....
Laurel Creek, from mouth to head	23	134	80	128	[a] 760	5,550	8,850	....	....	....
Ivy River, from mouth to Bull Creek	2	[b] 160	112	179	90	918	1,470	....	....	....
Ivy River, from Bull Creek to West Fork	2	[b] 110	77	123	180	1,260	2,020	....	....	....
Turkey Creek, from mouth to head	15	79	55	88	[a] 350	1,750	2,800	....	....	....
Swannanoa River, from mouth to North Fork	18	[b] 90	63	100	207	1,190	1,900	....	....	....
Hominy Creek, from mouth to head	19	100	70	112	[a] 210	1,340	2,140	....	....	....
Mills River, from mouth to North Fork, South Fork	5	[b] 71	88	141	90	720	1,150	....	....	....
North Fork, Mills River, from mouth to head	8	24	29	46	[a] 270	712	1,140	....	....	....
South Fork, Mills River, from mouth to head	......	43	60	96	[a] 570	3,110	4,980	....	....	....
Little River, from mouth to head	17	60	72	115	[a] 400	2,620	4,190	....	....	....
Davidsons River, from mouth to head	13	42	59	94	[a] 550	2,950	4,720	....	....	....
West Fork, from mouth to head	10	30	42	67	[a] 350	1,340	2,140	....	....	....
Total	......	....	....	....	......	26,290	42,060	....	....	....

[a] Mean head.

[b] Mean drainage area.

TABLE 49.—*Indicated horsepower developed by South Fork of Holston River.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
South Fork, Holston River:										
From mouth to Watauga River	*Miles* 18	*Sq. miles.* 1,940	*Sec. ft.* 776	*Sec. ft.* 1,160	*Feet.* 90	6,340	9,540	....	....	....
From Watauga River to Middle Fork	44	780	273	410	450	11,200	16,700	....	....	....
From Middle Fork to White Top Creek	4	350	122	183	90	999	1,490	....	....	....
From White Top Creek to head	32	[a] 165	58	87	[b] 350	1,850	2,780	....	....	....
Total	......	....	....	....	......	20,389	30,510	....	....	....

[a] Total area.

[b] Mean head.

Tributaries of South Fork.—Watauga River has a drainage area of 841 square miles. The indicated horsepower along this river is set forth in Table 50.

TABLE 50.—*Indicated horsepower developed by Watauga River and tributaries.*

Section of river.	Length.	Mean drainage area.	Minimum discharge.	Minimum discharge during 6 high-water months.	90 per cent total fall.	Minimum horsepower.	Minimum horsepower during 6 high-water months.	Horsepower available from storage during a period of—		
								12 months.	6 months.	3 months.
Watauga River:										
From mouth to Doe River.....	*Miles.* 20	*Sq. miles.* 760	*Sec. ft.* 418	*Sec. ft.* 627	*Feet.* 180	6,840	10,300	....	....	....
From Doe River to Roan Creek.	18	484	266	399	284	6,860	10,300	....	....	....
From Elk Creek to Cove Creek..	18	135	74	111	702	4,720	7,090	....	....	....
Doe River:										
From mouth to Laurel Creek..	6	127	64	96	225	1,300	1,900	....	....	....
From Tiger Creek to head..	14	[a] 65	32	48	[b] 670	1,950	2,920	....	....	....
Laurel Creek, from mouth to head..	12	[a] 28	14	21	[b] 850	1,080	1,620	....	....	....
Stony Creek, from mouth to head...	14	[a] 54	32	48	[b] 430	1,250	1,880	....	....	....
Roan River, from mouth to Doe Creek............	5	160	96	144	90	783	1,170	....	....	....
Roan River, from Doe Creek to head............	19	[a] 109	65	98	[b] 380	2,250	3,375	....	....	....
Elk Creek, from mouth to head..	24	[a] 80	48	72	[b] 770	3,360	5,040	....	....	....
Total.......	......	....	....	....	......	30,393	45,655	....	....	....

[a] Total area.

[b] Mean head.

Middle Fork is a tributary of the South Fork, having a drainage area of 231 square miles. Along the lower 19 miles of its course the fall is 150 feet and the minimum discharge 95 cubic feet per second, producing a minimum indicated horsepower of 1,170, and a minimum for the 6 highest months of 1,760.

White Top Creek, a tributary of South Fork, has a drainage area of 178 square miles. The fall in the lower 5 miles is 300 feet and the minimum discharge 72 cubic feet per second. There is produced a minimum indicated horsepower of 1,760, and for the 6 highest months 2,650.

NORTH FORK, HOLSTON RIVER.

North Fork has a drainage area of only 732 square miles, and its total length is 100 miles. In the first 70 miles of the river there is a fall of 500 feet, which will produce a minimum indicated horsepower of 6,460. The remaining 30 miles to the head of the river has a total fall of 800 feet, of which 230 may be considered as a reasonable working head. The minimum discharge is 55 cubic feet per second, which will produce a minimum of 1,150 horsepower. Big Moccasin Creek, a tributary of North Fork, 34 miles long, has a total drainage area of 93 square miles. It has a mean head of 570 feet. The minimum indicated horsepower produced by this stream throughout the entire stretch is 1,710.

CONCLUSION.

The facts given in previous pages require no further elucidation. Great as they show the water-power facilities to be, they do not convey an adequate idea of the immense possibilities of the region.

Approved:
JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *January 15, 1908.*

O

Walter T. Mulford

HOUSE OF REPRESENTATIVES, UNITED STATES
COMMITTEE ON AGRICULTURE

A REPORT

ON

"THE INFLUENCE OF FORESTS ON CLIMATE AND ON FLOODS"

PROPERTY OF DIVISI
FORESTR
COLLEGE OF AGRICULT
UNIVERSITY OF CALIFORN

BY

WILLIS L. MOORE, LL. D., Sc. D
Chief of the U. S. Weather Bureau

NOTE.—When Professor Willis L. Moore was before the Committee on Agriculture of the House of Representatives in 1909, to explain the estimates for the Weather Bureau, a discussion arose as to the influence of forests on climate and on the run-off of water. Professor Moore stated that he was then making some studies on the subject which might lead to some definite conclusions, and he was requested by the chairman of the committee to continue these studies and make a report when they were concluded. This has been done, and the report submitted by Professor Moore, which follows, is printed by direction of the committee.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

THE INFLUENCE OF FORESTS ON CLIMATE AND ON FLOODS.

By Willis L. Moore, LL. D., Sc. D., *Chief U. S. Weather Bureau.*

INTRODUCTION.

One of the most important problems before the American people to-day is the protection of their natural resources against either the greed of those who would monopolize them for their own individual benefit or those who, while well meaning, would through ignorance destroy our heritage and leave posterity poor.

In the discussion of matters concerned with the conservation of the natural resources of the nation, some of which may involve the expenditure of hundreds of millions of dollars and the employment for years to come of thousands of public officials, a consideration of the relation of forests to climate, floods, and low water is vitally important.

While much has been written on this subject, but little of it has emanated from meteorologists or from those in the public service who have been actively engaged in the forecasting of river stages, both of high and of low water. In the prosecution of such duty these officials have become acquainted with the physical facts involved in the problem and are therefore well fitted to speak on the relation of such facts to stream flow.

THE AUTHOR ACKNOWLEDGES A CHANGE OF OPINION.

It has frequently been stated that forests control the flow of streams, both in high-water stages and in low-water stages, and that the climate is so materially affected by the cutting away of the forests that droughts have largely increased and that the well-being of future generations is seriously menaced. It is my purpose to present facts and figures that do not support these views, some of which, especially those that pertain to the flow of streams, were held by me up to a few years ago—until a careful study of our own and other records and of the incidents of history caused me to modify my opinions. I shall endeavor not to be dogmatic, but rather to present the reasons for the conclusions that I now entertain, with, so far as may be, statistical and historical evidence to sustain them. And I reserve the right to change or still further modify my views if the presentation of new facts and figures render such a course logical, and do not consider that I shall stultify myself in so doing.

FORESTS SHOULD BE PROTECTED.

There are so many reasons why forests should be protected by the state and the nation and economically conserved in the interests of the whole people that it is doing an injury to a good cause to attempt to bring to its support the false reasoning and mistaken conclusions of enthusiasts, no matter how well meaning they may be or how devoted to high and lofty purposes.

Conservation of national resources is national economy, just as conservation of private resources is personal economy. But whether personal economy is beneficial or harmful to the individual and his children depends upon the extent and nature of that economy; and the same thing is equally true of a nation. Conservation that prevents the practical use of individual or national resources is like unto the economy of the timid servant that hid his master's talent in the earth, and in large measure deserves the same condemnation.

There should be neither wasteful use of resources nor that greatest waste of all, total disuse of them, but that economical use which in the end will have yielded the greatest good to the greatest number.

Preservation of the forests, cutting wisely, but never more than they reproduce, enables us to draw from a perpetual supply a certain quantity of material for buildings, for furniture, and for fuel. But of course the *forested land yields not a handful of wheat nor of corn and makes but a wretched substitute for the pasture upon which to feed milch cows and beef cattle.* These conflicting interests, the pleading of the poor man's children for bread and meat and the cry of the country for the lumber that only a woodland can furnish would, if there were no other interests to modify the result, somewhere find an inevitable balance. But just as the body is more important than its raiment, so, too, is its food more important than its shelter; and therefore in every country *the general tendency, with growth of population, is to convert forest lands into cultivated fields, and this tendency should not be discouraged unless it can be shown that deforestation has augmented droughts and floods, and I believe that it can not be so shown; I believe that forests should be preserved for themselves alone, or not at all.*

The average virgin forest is wasteful as a source of lumber and of fuel. It is only here and there that a tree is found of proper growth and suitable species for first-class material. As a lumber producer a forest of this kind is analogous to a cornfield planted in scattering hills here and yonder, instead of being cultivated throughout its extent and planted with that regularity and closeness of spacing that will produce the maximum yield. If the expense is not found to be too great in comparison with the return, forests should be cultivated with the same care both as to species and as to distribution, and possibly, too, as to rotation, that the intelligent farmer uses in planting his fields. In this way returns equal to what we now get could be secured from a much smaller forested area, and *there can be no valid objection to decreasing the area where homes and a well-fed people take the place of wild animals and the wilderness.*

It is found that in some limited areas where the forest is cleared away, the soil, owing to its nature and slope, will not admit of successful cultivation. It may wash so badly under heavy rains as to become unfit even for reforesting. In others, owing to the nature of the surface, cultivation is impossible. These are fit places for local control, provided such control is commercially feasible, but not for national control, *unless it can be demonstrated that the conditions at these places materially affect the navigability of streams or harmfully affect the climate of the continent at large.*

The great value of forests as fuel producers is admitted on every hand, and because of the growing cost of coal their importance in this particular is likely to increase rather than diminish, and of course without them the world would be deprived of that beautiful building material which from the earliest ages it has used so freely and regarded as indispensable, but which in the future may be used in a less ratio as the use of noncombustible materials, like concrete, stone, and steel, becomes more general, and certainly their use will increase. No reason in addition to these can be needed to justify an immediate and vigorous effort on the part of individuals, and especially on the part of governments, to teach and to insure the wisest national use—that is, wisest use when both the present and the future are properly considered—of all existing forests, and also where and how best to secure other forested areas.

Nevertheless additional reasons are urged, and in some cases urged as the paramount reasons for forest conservation, which will not stand the test of investigation.

EFFECT OF FOREST ON CLIMATE.

It is often said that the climate of a given place depends upon the extent and proximity of wooded areas; that the number of rainy days and the total amount of rainfall are modified by change of forest extent; that the depth of floods, the shallowness of low water, and the regularity of flow are all profoundly modified by changing the proportion of fields to forests in the watershed.

Now, the extent and even the nature of these influences is not a matter, as often is implied, of universal agreement. In regard to change of climate, regardless of the cause, trustworthy records of temperature, of rainfall, and of other meteorological elements do not cover a sufficient range of time to furnish all the data necessary for a *statistical* solution of this problem. However, there appears to be plenty of evidence that there have been times in the remote past when the salt seas both of Asia and of America had surfaces of greatly increased size over those that now exist. There is evidence also that in certain of these regions trees once grew more abundantly than is now the case. This, however, must not be taken as proof that there has been a decrease of rainfall due to destruction of the forests. It is true that the forests have diminished—in some cases wholly vanished—and it is also true that the evidence strongly supports the assumption of a decrease in rainfall, and therefore, of course, of a greater or less change of climate; but this decrease of precipitation might better be regarded as the cause rather than as the result of the barren condition of the soil. There is no evidence that the forests were ever more extensive in Alaska and in other high-latitude countries than they now are. Nevertheless, in these countries, too, just as in arid regions of the great continents, there is evidence of the same slow, long-period climatic change—a decrease of precipitation or an increase of temperature, or both—a change that can not be due to deforestation. This evidence consists in the slow irregular retreat (followed once in a while by a slight advance) and diminution of the glaciers, which phenomenon is said to be universal regardless of latitude, of longitude, and of elevation, and which appears to have been in more or less steady progress with, however, occasional temporary relapses of one or another magnitude since the culmination of the great ice age. In fact, we can reasonably say that we are even yet in the ice age—a vanishing age to be sure, but one not wholly gone—*and, further, that whatever marked climatic changes take place they are essentially universal and not local.*

Prof. William J. Humphreys, Ph. D., Johns Hopkins, professor of meteorological physics, United States Weather Bureau, says:

> These universal slow climatic changes that for thousands of years have been modifying the glaciers and changing the inland seas might very well have led to extensive forest destruction; but that it itself was the effect and the destruction of the trees the cause seems most unlikely.

DESICCATION IN ASIA.

In this connection I would refer to the opinion of Mr. Ellsworth Huntington, B. A. of Beloit and M. A. of Harvord. For four years, 1897–1901, he was the President's assistant and instructor at Euphrates College, Harput, Turkey. He explored the canyon of the Euphrates River in 1901 and was awarded the Gill Memorial by the Royal Geographic Society of London. He was research assistant in the Carnegie Institution, of Washington, and was a member of the Pumpelly expedition to Russian Turkestan in 1903–4. He spent one and one-half years in Turkestan and Persia and a like period in India, China, and Siberia as a member of the Barrett expedition. He has been instructor in geography at Yale since 1907. He explored the Lop basin in Chinese Turkestan, whose length is 1,400 miles and whose maximum width from north to south is 400 miles, embracing an area as large as that portion of the United States east of Lake Michigan and north of Tennessee. Most of the basin is desert. In an article in the Monthly Weather Review for November, 1908, dated at Yale University, November 10 of the same year, he says:

> The Lop basin contains abundant evidences of climatic changes, and has been discussed in detail by the writer in "The Pulse of Asia." Throughout the basin the amount of vegetation has greatly decreased in recent times without the intervention of man. On the lower slopes of the Kuenlun Mountains the dissected condition of numerous deposits of loess shows that a cover of grass prevailed at no remote date, but has now disappeared. In the zone of vegetation plants of all kinds show signs of a process of drying up which has been in progress for centuries. Tamarisk bushes stand upon mounds from 5 to 60 feet high, a sure sign of the lowering of the level of ground water; poplar forests which once extended for scores of miles now form wastes of branchless dead trunks like gaunt gray skeletons; and beds of dead reeds cover hundreds of square miles. It has often been asserted that the destruction of forests has been the cause of the diminution of rainfall. In the Lop basin the opposite appears to be the case; the supply of water has diminished, and therefore the forests have died. Rainfall unquestionably controls forestation, but neither in the Lop basin nor in other parts of central and western Asia is there any good evidence that forests have an appreciable effect upon rainfall.
>
> Another important line of evidence is found in the relation of rivers to the desert of Taklamakan and to ruins of ancient dwellings. On the south side of the Lop basin, from Khotan eastward to Lop Nor, the writer examined seventeen streams which are worthy of notice, because of their size or because they support oases. All but four come to an end in the zone of vegetation, where they spread out and disappear either naturally or because used for irrigation. Hence it is impossible to determine whether

or not they have decreased in length. At the lower ends of the other four, old channels are found lined with dead forests, which prove that the streams once extended from 8 to 25 miles farther than is now the case before finally becoming swallowed up in the sand.

FORESTS IN EVIDENCE AFTER STREAMS HAVE DRIED UP.

The fact that dead forests stand long after the streams have receded seems to prove that they are the last to disappear rather than the first, and therefore that their removal did not precede the drought but rather that the forests ceased to exist when the rainfall became deficient. Unmistakable evidence is found of the existence of extensive forests in Arizona and New Mexico, where only the petrified trunks of trees now remain. It can not be said that man removed these forests and brought on the drought.

LOCAL CLIMATIC INFLUENCES OF FORESTS.

One may conclude from the evidence gathered from many sources that summer temperature is slightly less in the forests and in their neighborhood, especially to the leeward, than it is in corresponding cleared sections. Forest temperature is also slightly higher during cold weather than is that of open fields, due presumably to the interference of the trees, even when of the deciduous type, with free ground radiation.

The increase of winter temperature, however, is not equal to the decrease of that of summer, the season during which most vegetation needs all of the heat it can get; and, therefore, it happens that wooded areas may slightly retard the growth of crops in their neighborhood, as is said to be the case in the uplands of Mauritius.

With regard to the effects of forests on rainfall, I quote the following from recent writings of Prof. Cleveland Abbe, who is the senior professor of the Weather Bureau and a member of the National Academy of Science. He says:

> It is a pity that the errors of past centuries should still continue to be disseminated long after scientific research has overthrown them. It is easy to start false theories and to believe them, because they are generally simple and plausible, but long years of work are necessary before we get at the secrets of nature. In this day and generation, the idea that forests either increase or diminish the quantity of rain that falls from the clouds is not worthy to be entertained by rational, intelligent men.

Gauges exposed over forests universally catch more than gauges exposed at the same elevation in the open. Professor Abbe explains this as follows:

> The main trouble consists in the assumption that the water caught and measured in the rain gauge correctly represents the rainfall. Perhaps the most interesting observations bearing directly on this question are those made by Brandis and Blanford in India, where rain gauges were placed both on the ground and above the tree tops at the height of 60 feet in well-watered regions. The high gauges in the forest recorded 4 per cent greater catch than those at the same height in the open fields, and the low gauges on the ground in cleared spaces in the forest gave 2 per cent greater catch than those in open lands. But these figures do not prove that the forest received more rain than the clear areas, although at first sight they would seem to confirm that idea. The fact is that the forest gauges were better sheltered from the wind than the open-ground gauges and this caused them to catch a larger proportion of the rain that fell.
>
> The rain gauge has several sources of error that must be investigated and allowed for, as in all other meteorological apparatus, so that we may not use crude and imperfect data. The effect of the wind in diminishing the catch of the rain gauge has frequently been investigated since the first studies by Mikle in 1819, and the present state of our

knowledge was convincingly summarized * * * in 1887 in an Appendix to Bulletin 7, published by the Forestry Division, United States Department of Agriculture. This Bulletin, edited by B. E. Fernow, "the father of American forestry," recounts the various methods appropriate to the determination of the true amount of precipitation, and its bearing on theories of forest influences.

It appears that in ordinary rainfalls we have a mixture of large and small drops of water descending with various velocities that depend on their size, density, and the resistance of the air. Particles of hail descend even faster than drops of water, but flakes of snow fall more slowly. When the wind strikes the side of a rain gauge the deflected currents move past this obstacle more rapidly, and there is an invisible layer of wind above the open mouth of the gauge, whose horizontal motion is more rapid than that of the wind higher up. Some of the larger falling drops may descend with a rapidity sufficient to penetrate this swiftly moving layer of air, but the slower ones will be carried over to leeward and many will miss the gauge. The resulting loss of rain will depend upon both the horizontal velocity of the wind and the vertical velocity of descent of the rain.

The fact that the deficit increases with the velocity of the wind (which is less over the forest) has also been proven in a different way, viz, by shielding the gauge from the wind, when the deficit becomes greatly reduced in value. Professors Henry, Nipher, Boernstein, Hellmann, all of them eminent investigators, agree in this conclusion.

Of two gauges exposed at the same elevation above the ground, one over the open fields and the other over a forest, just above the tops of the trees, the one over the forest will catch considerably more rain, because the friction of the trees reduces the velocity of the wind and it does not rush across the open end of the gauge with the same speed that it does across the gauge over the open fields.

The influence of a forest upon the rainfall is therefore only apparent; it may increase or diminish the *catch of the gauge*, but not the quantity of *rain falling from the cloud.*

Professor Abbe further says:

If gauges are raised up year by year, the deficit increases; if gauges in open fields become surrounded by growing trees or higher buildings, the deficit decreases. The *climate* has not changed, but the *errors* of the *record* have done so. Those who wish to restore the good old times before the forests were cut down, when rain and snow came plentifully and regularly, have only to lower and shelter their rain gauges and snow gauges and, *presto*, the climate has changed to correspond.

When rain is falling on a forested region, about 25 per cent is temporarily held far above the ground on the leaves and branches of the trees. In this minutely divided condition, exposed to the action of the wind, the drops evaporate freely, so that the forest atmosphere becomes saturated and decidedly less moisture reaches the ground to be absorbed in the forest humus than on an equal volume of soil outside the forest. A special climate is therefore maintained within a forested area. The temperature is lowered and the relative humidity is increased, but there is no evidence that this local forest climate extends outside the forest or affects exterior conditions to any important extent. Of course, the climate under a tree or a tent or within a house differs from that outside, but these are local matters quite foreign to the broad question, Do forests affect climate?

The climate within a house is not the climate of the whole city, nor is the climate of a ravine that of the surrounding fields. One thermometer or rain gauge in the open air does not give the climate of a State or watershed. The various and restricted uses of the word "climate" have led to our confusion.

LOCAL TEMPERATURE DIFFERENCES DUE TO CHARACTER OF SOIL COVERING.

As the result of investigations begun in Wisconsin by the author over fifteen years ago and continued during the past three or four years by Prof. Henry J. Cox, of the Weather Bureau, we have found that surprising results are obtained on two surfaces of precisely the same level on adjacent fields, one of them covered with thick vegetation and the other covered 2 inches deep with sand. We have noted differences in temperature frequently of 7° to 9° in the air immediately adjacent to the surface or within a stratum 3 inches deep, this difference being so great that one area would receive a heavy deposit of frost and the other (sanded section) be entirely free from such frigid temperatures; and the difference in temperature between a thermometer exposed in the heart of a city and one in the open field but a few miles away was found to be marked. As an illustration: A thermometer in a shelter at La Crosse, Wis., registered 50° minimum temperature on a certain morning, while a thermometer in the cranberry marshes 50 miles away fell to freezing; but these were all local irregularities. The difference in temperature between the air over thick vegetation and that over the sanded surface disappeared within a height of 3 feet, and it is probable that the temperature over La Crosse and over the cranberry marshes was the same at an altitude of 200 feet.

CHANGING THE LOCAL CLIMATE BY ARTIFICIAL CONDITIONS.

The covering of tobacco plants with thin cheese cloth results in establishing a local climate which will continue so long as the cheese cloth remains in position. The extremes of temperature, both heat and cold, are reduced, and the resulting climatic change produces a marked effect upon all vegetation grown under the artificial conditions. The erection of a tent, of a barn, of a dwelling house, of a village, or the growth of a great city, respectively, influence the local climate in proportion to the area that is covered, modified by the character of the material used in these constructions. Likewise the vegetable covering of the earth may have a local appreciable effect. The flooding of an area, the cutting away of forests, erosion, and sanding may have either minute or appreciable effects upon local climates in proportion to the magnitude of the areas affected, *but this does not mean that there is any great difference in the climatic effect between a forest covering and one of bushes, of grass, or of growing crops; and it does not signify that there is sufficient change in the thermal conditions, due to the activities of man, as to make an appreciable difference in the temperature at an altitude of one or two hundred feet, or to affect the general climatic conditions, or to cause storms to be more frequent than formerly or of greater severity, or to increase the amount of precipitation.*

A PLEA FOR TOLERANCE OF OPINION.

But this discussion should not be approached in an intolerant spirit. We have accurate records of climate from only a few isolated places in this country that extend back for a period of as much as one hundred years, and the Government's extensive records only cover a period of forty years. I would warn against hasty conclusions; against accepting as final the deductions of several investigators who have recently publicly discussed the flood records of the Weather Bureau. They find a most alarming increase in the floods of the Ohio Valley and other places, for which I find no justification. Let logic, reason, and investigation have time to operate, for any man may be honestly mistaken and draw general conclusions from inconsequential details or deceive himself by the improper grouping of data.

RECORDS OF PRECIPITATION SHOW NO MATERIAL CHANGE.

The records of precipitation of the United States Weather Bureau do not show that there has been any appreciable permanent decrease in the rainfall of any section of the United States. There are undoubtedly periods covering a number of years of continued deficiency in precipitation for certain districts, but at the same time other districts may show a corresponding increase. One of the best and longest records of precipitation of the eastern part of the country is that made at New Bedford, Mass., by Mr. Samuel Rodman and his son, covering the period from 1814 to within a year or so ago, a period of about ninety-five years. The following table shows the annual amount of precipitation during each year of the above-named period, from which one can see for himself the variations in the amounts from year to year, by the ten-year period, or make other comparison:

TABLE 1.—*Annual precipitation at New Bedford, Mass., for the period, 1814 to 1908.*

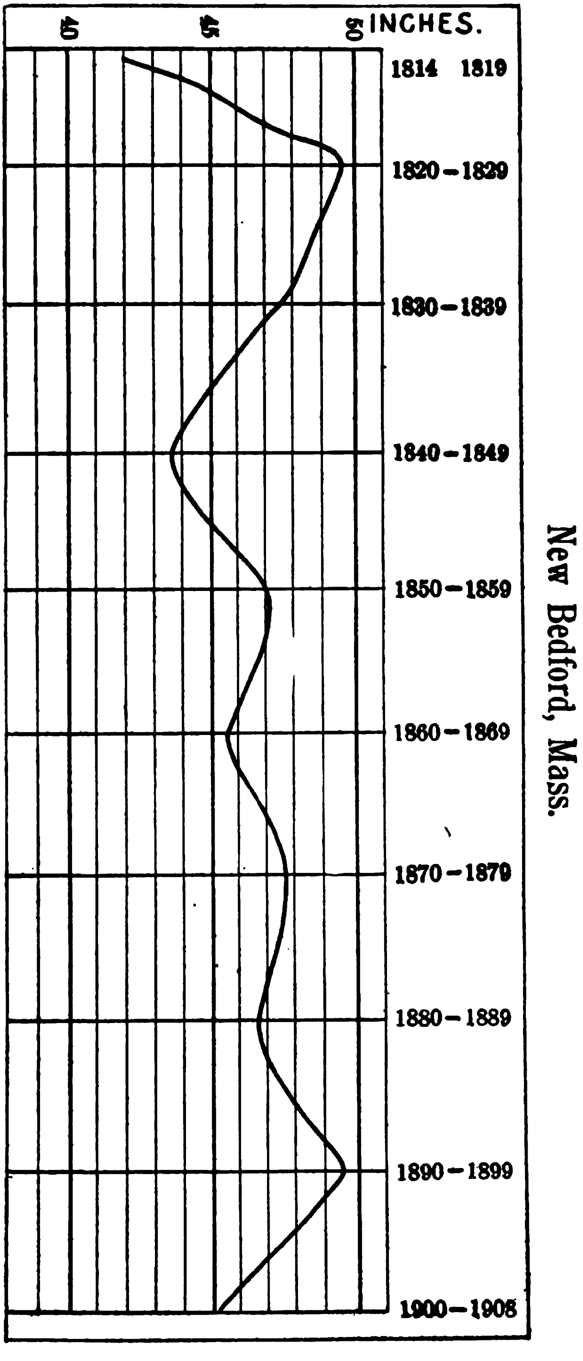
Year.	Amount.	Year.	Amount.	Year.	Amount.	Year.	Amount.	Year.	Amount.
1814	43.06	1833	42.62	1852	46.14	1871	49.60	1890	61.69
1815	40.78	1834	45.12	1853	39.47	1872	47.66	1891	47.83
1816	44.13	1835	47.21	1854	53.82	1873	51.70	1892	42.83
1817	43.33	1836	42.83	1855	41.00	1874	49.34	1893	50.27
1818	40.77	1837	39.07	1856	37.09	1875	48.33	1894	45.89
1819	39.66	1838	38.28	1857	43.30	1876	42.18	1895	41.63
1820	41.32	1839	44.38	1858	44.03	1877	47.04	1896	47.73
1821	45.64	1840	45.59	1859	51.43	1878	50.56	1897	50.96
1822	41.78	1841	50.60	1860	39.73	1879	42.31	1898	62.60
1823	59.89	1842	39.06	1861	46.46	1880	40.07	1899	44.34
1824	47.34	1843	50.67	1862	43.32	1881	39.10	1900	44.99
1825	38.09	1844	40.73	1863	45.10	1882	41.38	1901	51.84
1826	54.77	1845	48.06	1864	40.96	1883	43.51	1902	45.42
1827	62.90	1846	34.51	1865	46.01	1884	54.99	1903	47.49
1828	39.04	1847	45.91	1866	40.30	1885	36.81	1904	50.08
1829	65.41	1848	40.74	1867	47.11	1886	49.85	1905	41.30
1830	64.66	1849	36.42	1868	56.32	1887	51.77	[a] 1906	43.09
1831	61.18	1850	62.67	1869	49.94	1888	55.07	1907	42.32
1832	49.31	1851	51.61	1870	47.16	1889	52.71	1908	38.61

[a] The record for New Bedford ends with the year 1906; annual amounts for 1907 and 1908 are for Fall River, Mass.

The average fall for ten-year periods from 1814 to 1908, inclusive, indicates that while the rainfall during the past few years has been considerably less than the average, it has not been less than has occurred in numerous previous years—notably from 1814 to 1819, from 1833 to 1839, and from 1860 to 1866. Further investigation shows that for the first fifty years of the period the average annual rainfall at that point was about 46 inches, while during the last forty-five years the annual fall has increased to more than 47 inches. *This indicates that instead of a diminishing rainfall we have the evidence that, if there is any variation at all in the precipitation, it is a slight increase for this region.*

Figure 1 graphically shows the average fall for ten-year periods, namely, from 1814 to 1908, inclusive.

We will now move our inquiry to a part of the Middle West where there has been no deforestation. Here there has been a growth of planted hedge rows, of trees along highways and fence lines and about places of habitation, and the virgin soil has been broken and made more permeable to the rainfall.



New Bedford, Mass.

Fig. 1. Average rainfall in ten-year periods.

The annual fluctuation in precipitation for two different parts of the United States, viz, New England and the Ohio Valley, is graphically shown in figure 2. The New England curve was constructed from the data for Boston, New Bedford, and Providence, at which points fairly accurate rainfall measurements have been made dating back to 1836. The Ohio Valley curve is based upon rainfall measurements made at Marietta, Portsmouth, and Cincinnati.

The heavy horizontal lines in the diagram represent the normal precipitation. The amount that the actual fall of any year exceeded or fell short of the normal may be found by noting the intersections of the curved lines with the smaller horizontal lines, whose values are given in inches on the left margin. If periods of heavy and light rainfall alternated regularly, the lines of departure from the normal (the curved line) would rise and fall in a series of bends or inflections precisely as the temperature rises and falls with the alternation of day and night. Reference to the diagram itself will best show how closely the rainfall of the two regions approaches any sort of periodicity. The Ohio Valley curve is more symmetrical than that of New England, and there appears to be a rough periodicity of about nine years in it. Thus there were periods of heavy rainfall about 1837, 1847, 1858, 1866, 1875, 1882, and 1890, and of drought in 1839, 1856, 1863, 1871, 1878, 1886, and 1895.

A comparison of the two curves illustrates the fact elsewhere referred to that the rainfall over a region so large as the United States is not by any means uniform in its distribution. Thus the period of relatively light rainfall in New England during 1880–1883 was one of heavy rainfall in the Ohio Valley and elsewhere in the great interior valleys. Likewise in 1878 there was heavy rainfall in New England and light rainfall in the Ohio Valley.

In New England, where deforestation began early in our history and has been extensive, the mean of the fluctuations in the rain curve is a steady rise since 1836 up to a few years ago, and in the Ohio Valley, where the forest area has been greatly diminished, there is no decrease of rainfall shown by the average of the fluctuations of the curve. These facts are important and can not be successfully disputed.

GOVERNMENT RECORDS VERSUS RECOLLECTIONS OF OLDEST INHABITANTS.

It is the duty of the United States Weather Bureau to publish information with regard to climatic conditions; and in this connection I would call particular attention to the fact that the government records are in a class separate and distinct from the recollections of the oldest inhabitants, which are entirely untrustworthy, no matter how truthful the persons intend to be. These recollections do not justify the claim that the forests have increased precipitation, for it is almost the universal opinion of the maturer man that the climate is milder and that the snows are less deep than when he was a boy. He remembers the long tramp to the little red schoolhouse in snow knee deep, but he fails to take into consideration the fact that a snow knee deep to a boy of nine years of age is no inconvenience to a man of six feet two. Human recollection can only recall from the dim past unusual storms—conditions that were abnormal, and these abnormalties are what the man of fifty or sixty years to-day believes to have been the average when he was young. In other words, the individual recollection should be given little weight in determining a matter that requires careful calculation and the preservation of accurate daily records before anything like safe conclusions can be reached.

THE EFFECT OF FORESTS ON FLOODS.

I have always held to the opinion that the cutting away of forests has had little or no appreciable effect on the amount of precipitation or on the general temperature. But until recent years I did believe that deforestation had an important and beneficial effect on the conservation; that is, on the economical use of the rainfall, and that forests restricted the run-off. But study and investigation have caused me to modify my views.

Professor Abbe says:

> The cultivated soil outside the forest, when plowed and broken open down to a depth of 8 inches, acts as a sponge to retain water quite as well as does the ordinary humus of a forest, especially when we consider that under a forest less rain actually enters the humus. In fact such measurements as have been made show that the amount of water that is eventually given up from the forest humus varies but little from that given up in the course of time by the unforested, cultivated soil. The total run-off from the two regions does not eventually differ greatly, but it does differ in the speed. However, it may be neither the amount nor the speed of run-off from the soil that determines the occurrence of river floods. We must distinguish between the soil run-off and the river run-off. When water has once entered the river channel its movements are determined wholly by the force of gravity, the curvature, the section, and the slope of the channel. Floods may occur in every small tributary and yet these waters may so enter the main channel as to produce only a gentle rise throughout its whole length. At other times the smaller elementary floods may conspire and produce a specially disastrous flood in the main channel. Therefore the occurrence of disastrous floods does not depend on rainfall alone or wholly on soil run-off, but equally and principally on the relative times at which floods occur in the individual tributaries, and the time required by them all to reach and combine at any given point in the main channel.

This is a tangled problem, since the result must depend upon the slope of the ground; the nature and condition of the soil; the nature of the forest, whether deciduous or evergreen; the nature of the general climate of the place, whether it has cold, snowy winters or rainy ones, and whether the spring merges gradually or abruptly into summer; upon the use or treatment of the cleared surface; and probably upon other conditions.

The foresters are generally in accord in the belief that the forests exercise a marked restraining influence on floods and a conserving influence on precipitation, even if they do not actually increase, by an appreciable amount, the rainfall. On the other side, army and civilian engineers and meteorologists generally believe that the broken, cultivated, permeable soil, which is covered for a greater portion of each year with millions of the rootlets of growing grasses and cereals, is equally as good a conserver of the rainfall as the forest area itself, even though the latter has the advantage of the deep boring of large roots into the substratum; that the evergreen forests prevent the drifting of the snow and at the same time their heavy foliage protects the snow from the sun and permits a slow melting, which is all absorbed by the forest cover until it is saturated, and then with further heat the water breaks out in a flood; that the function of deciduous forest trees is to catch the falling snow, distribute it equally over the surface, and thus facilitate more rapid melting by causing the snow to present to the warm air a greater melting surface than it does in the open, where wind drifts it into banks in the lee of opposing objects and stores it in depressions and ravines, so that it may remain for a considerable time after the evenly distributed blanket has disappeared from the forests.

It has been shown by Chittenden that in Yellowstone Park and similar mountain regions the forests protect the snow from drifting, melting, and evaporating, while in the open there is much drifting and an early clearing up of those places well exposed to wind and to sunshine; therefore, when warm weather and its rain come on abruptly, and come to stay for the summer, as they do in those regions, the melting of the snow in the forests, because of the greater area exposed, the surface being uniformly covered, is far more rapid than it is in the open where it is badly drifted, and leads to higher freshets and less enduring run-offs. *On the whole, it is probable that forests have little to do with the height of floods in main tributaries and principal streams, since they occur only as the result of extensive and heavy rains, after the ground is everywhere saturated, or when heavy warm rains come on the top of deep snows.*

RUN-OFF AND ABSORPTION.

Concerning the surface run-off, it appears to be generally held that when the rainfall is small, the dead leaves, the moss, the tangle of undergrowth, and the like, in the forests may modify or entirely prevent flow, and may slightly intensify low-water conditions of summer, while on the cleared surfaces, except that of freshly-cultivated fields, this is not so markedly the case. When the rains are heavy and continued, there is surface flow in the forests as well as in the open, and the two do not materially differ, for it can be shown that the run-off from a smooth surface and from one covered with sticks, dense grasses, or forest, are equal after the rough surface becomes saturated, and it is long after *all surfaces* have become saturated that flood conditions can occur.

Because of their open, porous condition sandy soils and freshly plowed fields are the best absorbers, and in general forest ground is thought to be more penetrable to moisture than is that of the cleared fields, except when the latter are freshly broken, but the greater part of the cleared land is either broken and cultivated several times during the year or else it is occupied by vegetation that exercises either partly or wholly as great a conserving influence as the forest.

All of these problems could be definitely settled beyond the possibility of argument if we had accurate river gaugings from day to day and year to year, together with a full knowledge of the rainfall and of the proportion of the wooded to cleared areas, data that unfortunately we do not have. We must, therefore, reason empirically from the best information at hand, and this insufficiency of data renders less positive the conclusions of all investigators, no matter which side of the question they may be on.

EFFECT OF FORESTS ON FLOODS IN FRANCE.

An important contribution to this discussion was made in 1873 by Capt. Charles J. Allen, of the Engineer Corps, U. S. Army, in the translation that he made of extracts from the work of M. F. Vallès, which treats of the influence of forests on floods and inundations.

This translation contains quotations from the works of M. Belgrand and other French engineers, who had made the hydrology of the basin of the Seine a special study.[a] Among other things M. Belgrand says:

> This country comprises all or part of 21 Departments, as follows: Aisne, Ardennes, Aube, Cote d'Or, Eure, Eure-et-Loire, Loiret, Marne, Haute-Marne, Nievre, Nord, Oise, Pas-de-Calais, Seine, Seine-Inferieure, Seine-et-Marne, Somme, Vosges, and Yonne, and comprises an area of about 107,000 square kilometers, nearly equal to the fifth part of the area of country comprising the 86 Departments.
>
> The most irregular streams, those most subject to rapid rises, are found especially in the Departments of the Yonne, Nievre, and Cote d'Or, and to a less extent in those of the Aube, Haute-Marne, and Aisne. This region is very woody, more so, perhaps, than the rest of France. The most remarkable Departments in regard to the regularity of the water courses which rise within them are the Eure, Eure-et-Loire, Nord, Oise, Pas-de-Calais, Seine-Inferieure, Somme, the chalky parts of the Aube and of the Marne, and those portions of the Seine-et-Oise and Loiret in which the limestones of La Beauce abound. The majority of the streams in these countries are subject to slight rises of short duration, their stage of water varying but little. This group of Departments is perhaps one of the most sparsely wooded in France, because the Eure, Eure-et-Loire, Nord, Oise, Pas-de-Calais, Seine-Inferieure, and the Somme have only about one-tenth of their surface wooded, and the plateaus of La Beauce and the chalky plains of Champagne are, if we except some recent plantations of pine, completely bare of trees.
>
> In order to test the question as to the effect of forests in regulating the flow of water M. Belgrand had daily measurements made from November, 1850, to May, 1853, of the discharges of the Cousin and of the Grenetierre, which is one of its affluents. Both of these basins are of granite formation, impermeable and otherwise alike, but the first is only about one-third wooded, while the second is entirely covered with trees. Notwithstanding this great difference as regards the extent of forests in each, the results have been the same in both, as is shown by the following account:
>
> "The regimen of each is identically the same, although their valleys are unequally wooded. Their waters rise and fall at the same rate, whether in rainy weather or in dry, in winter or in summer; their low winter regimen is more abundant than that of summer.
>
> "A heavy rain in winter produces in both a sudden flood of greater or less height, but of very short duration, followed by a long stage of tolerably high water; the sudden and high freshets take place in each at the same time."
>
> The different details concerning the flow of water are, then, exactly the same in the two basins, and yet one is entirely covered with forests, while in the other two-thirds is bare of trees. M. Belgrand has made a number of more detailed observations yet, which show, further, that it is not upon forests but upon cultivated ground that the greatest regularity in flowage is observed. * * *

In Vallès's paper he quotes from a report on the basin of the Eure made by M. St. Clair, engineer in chief, showing the beneficial effects of cleared and cultivated lands in diminishing by absorption the amount of surface water, as follows:

> All the valleys, even those of least extent, are cut up by ravines which were often formerly the beds of torrents. Within the last twelve years the condition has changed; they are now almost always dry. The cause of this great change, the progress of agriculture, is generally recognized in the country. The soil has been cultivated more and rendered more permeable; the farmers, reaping more advantages from the culture of the ground, and fully aware of the utility of improving it, have, by means of ditches, hedges, and endikements properly located, controlled the flow of water everywhere, preventing erosion, causing fertilizing deposits of sediment, and relieving the surface of the ground from the asperities which interfered with cultivation. The waters, retarded thus in their flow, have settled in great part through the ground and disappeared before reaching the ravines.
>
> These agricultural improvements, in a country where land susceptible of cultivation, amounts to sixty-one one-hundredths of the area of the country, have, then, reduced the surface flowage and increased the absorption.

---

[a] Annales des Ponts et Chausseees, annee 1852, premier semestre, p. 102.

They have rendered less frequent and formidable the freshets, which, in the basin of the Eure, are to be attributed to an excess of surface water rather than to any supply from springs, which latter is almost always invariable.

The effect upon springs of cutting down forests can now be easily eliminated. We will divide them into two classes, viz, superficial and subterranean.

The first issue from the points of the surface very near to the strata in which the waters which produce them collect. The second, on the contrary, are found very far below these strata, and the water, in order to find an outlet, traverses frequently long distances underground.

The first, generally small, pertain indifferently to absorbent or nonabsorbent ground; but the second, occasionally very powerful, pertain essentially and almost exclusively to permeable soils.

Now, it is indisputable that the continual humidity of the soil of forests is favorable to the first and ought to maintain in their feeble flow considerable regularity. It is, then, very likely that the clearing away of forests and exposing the earth to alternations of drought and moisture would alter the regimen of these springs; that these would be more abundant in time of rain; that they would decrease in summer and possibly be dry for several months in the year. This explains the disappearance of certain springs after the cutting down of forests.

As regards the second group, which are plentifully supplied by infiltration through the permeable soils, it is different.

From the different manner in which, as regards absorption, wooded and cultivated soils act, we see that in the first this faculty is in great part destroyed, while in the second it is increased. To remove standing timber from permeable soils is to restore to them the facility of transmitting the waters which the forest vegetation, whether by the spreading of its roots, by the fall of leaves, or by the compactness of the soil, had taken from them, and it results, consequently, in a more abundant supply of water to the subterranean springs.

Thus, it is worthy of remark that the most abundant of all of them, especially in seasons of low water, are located beneath the vast ledges of limestone which are almost entirely denuded; for instance, those of Cahors and Louysse, in the department du Lot, and the famous fountain of Vaucluse, of which mention has already been made.

M. Belgrand further says:

Now these basins, so remarkably alike, we have; they are those of the Seine in the seventeenth, eighteenth, and nineteenth centuries. Everything in these is alike excepting the extent of the forests, which has steadily decreased, so that if we were in possession of adequate information of some exact measurements of the greatest inundations during the time specified, we could easily test the correctness of our theories.

In fact, observations of this nature have been made; they go back to 1615, about the time when French industry began to develop, and when, consequently, the felling of timber to a great extent commenced.

This places at our disposal an interval of five half centuries.

In a memoir published in 1814 by the engineer Egault, these observations were compiled, discussed, and arranged with reference to the heights of the most marked inundations. We add to the results collated by them those which have been obtained since his time and give them in the following table:

Dates of the inundations.	Height at the bridge of La Tournelle.	Mean per half century.
	Feet.	*Feet.*
July 11, 1615	29.99	27.53
January, 1649	25.10	
January, 1651	25.59	26.36
March 1, 1658	28.87	
March, 1690	24.61	
March, 1711	24.77	25.34
December 25, 1740	25.92	
January, 1751	21.98	22.42
November 14, 1764	22.97	
March 4, 1784	21.85	
February 4, 1799	22.87	
January 3, 1802	24.44	21.22
March 3, 1807	21.85	
May, 1836	18.66	
February, 1850	19.91	

> The deductions from this table are striking. The continued decrease of the floods for each half century is remarkable. The waters attained a mean height of 27.53 feet in the first half of the seventeenth century; they only attained a mean of 21.22 feet in the present. According to this, we have experienced an amelioration of nearly 6.56 feet, and yet the trees have been steadily and unceasingly cut down, and the forests transformed into cultivated farms.
>
> What would we gain, then, to-day, I ask, in rewooding our field? It would be but an unfortunate attempt to restore the old order of things, when the floods of the Seine rose to 29.53 feet above the low stage.

In connection with the conclusions reached in this report, as well as with regard to those reached by the foresters and others who differ from my views, I would emphasize the fact that none of us have flood data extending over any great period of time, but in Europe we fortunately have some long-period observations. The preceding pages show the result of observations made by competent engineers during two and one-half centuries in the basin of the Seine, and show that there has been a gradual and constant decrease in the height of floods with the diminution of forests.

In Germany another long-period record is presented. Mr. Ernest Lauder, chief of the hydrographic bureau of the Austrian Government, recently made an exhaustive investigation of the records of the Danube, the great river of central Europe. He prepared an exhaustive report on the destructive floods in the Danube that occurred in 1897 and 1899, and in this report traces the history of the floods of the Danube for eight hundred years, taking into account 125 different floods. His conclusions are that progressive deforestation of the country has had no effect in increasing the frequency of floods or in augmenting their height. Among other things he showed that the flood of 1899, which was a summer flood, was severest where it came from the heavily wooded districts.

Much has been written about the barren condition of the valley of the Jordan, in the Holy Land, and it is pointed out that great cities and teeming populations once covered the regions now barren; but this does not prove that if there has been a decrease in the rainfall it is due to deforestation, for everywhere in this region are evidences of extensive irrigation that was practised at the time this region was thickly populated. The date palm, the vine, and the fig tree will grow there as luxuriantly to-day as in the old Biblical days, if artificial irrigation is used, as was formerly done. It is not believed that the cutting of the cedars of Lebanon has had anything to do with the dryness of the adjacent regions.

At the tenth International Congress of Irrigation, held at Milan in 1905, papers were presented by representatives from France, Germany, Italy, Austria, and Russia, in which the writers heartily favored the protection of the forests and their cultivation. But these writers were unanimous in the opinion that forests exercise little influence upon either the high water or the low water of rivers.

In this connection I will quote from Col. H. M. Chittenden, M. Am. Soc. C. E., volume 34, page 944, Proceedings of the Society of Civil Engineers, as follows:

> The constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it. There are, it is true, periods when floods are more frequent than at others, and hasty conclusions are always drawn at such times; but, taking the records year after year for considerable periods, no change worth considering is discoverable. The explanation of these periods of high water, like the one now prevailing, must, of course, be sought in pre-

cipitation. That is where floods come from, and it is very strange that those who are looking so eagerly for a cause of these floods jump at an indirect cause and leave the direct one entirely untouched. In the records of precipitation, wherever they exist, will be found a full and complete explanation of every one of the floods that have seemed unusually frequent and severe in recent years.

THE SOURCE OF FLOOD WATERS IN THE UNITED STATES.

Before one can get a comprehensive idea of the magnitude of the problem involved in the creation of the floods of the United States, it will be necessary for him to first study chart A, which gives a typical illustration of the cyclonic storms that frequently form on the Rocky Mountain Plateau, either on its northern, central, or southern portions. Under the influence of gravity air flows from regions where the pressure is great toward the regions where it is less. In the case illustrated by this chart the atmosphere, as indicated by the direction in which the arrows point, is flowing from the region marked "high," which is central over the Carolinas, toward the region where the pressure is low, which is central over Montana, and the vaporous atmosphere that rises from the Gulf of Mexico and the adjacent ocean is carried far into the interior of the continent. Conditions similar to these occur many times each month, and as a result the eastern and central portions of the United States are bathed in a succession of rains which, as shown by chart B, gradually thin out and largely disappear on the eastward edge of the Rocky Mountain Plateau, because the currents of air from the Gulf of Mexico do not reach farther inland.

STATEMENT BY MR. BAILEY WILLIS.

In the May issue, 1909, of the magazine entitled "Conservation," page 262, Mr. Bailey Willis makes the statement:

> The moisture which falls upon North America in the form of rain and snow comes chiefly from the Pacific Ocean. A smaller proportion, rising from the Gulf of Mexico and the West Indian seas, falls upon the eastern United States.

It is true that chart B, giving the normal annual precipitation indicates that the Pacific Ocean furnishes precipitation that is heavy along the immediate coast, but that it is the principal source, as Mr Willis says, of the moisture that falls upon the North American Continent, is not borne out by the facts exhibited by the precipitation chart herein produced and by the inflowing currents of air that are shown on chart A.

The range of mountains on the Pacific coast intercepts the inflow of the vaporous atmosphere, which is comparatively shallow, and precipitates its aqueous vapor on the windward side of the range, and mainly on the north half of the windward side, because storms seldom enter from the southern half. To be sure, some of the scant precipitation that falls on the plateau does drift over the tops of these mountains, but the amount is small. Certain it is that the Pacific Ocean has little influence on the precipitation of the eastern half of the United States, which fact is well understood by meteorologists; and I believe that most of them will join me in the belief that the only way that man could materially affect the rainfall of the eastern half of the United States would be to erect a mountain barrier

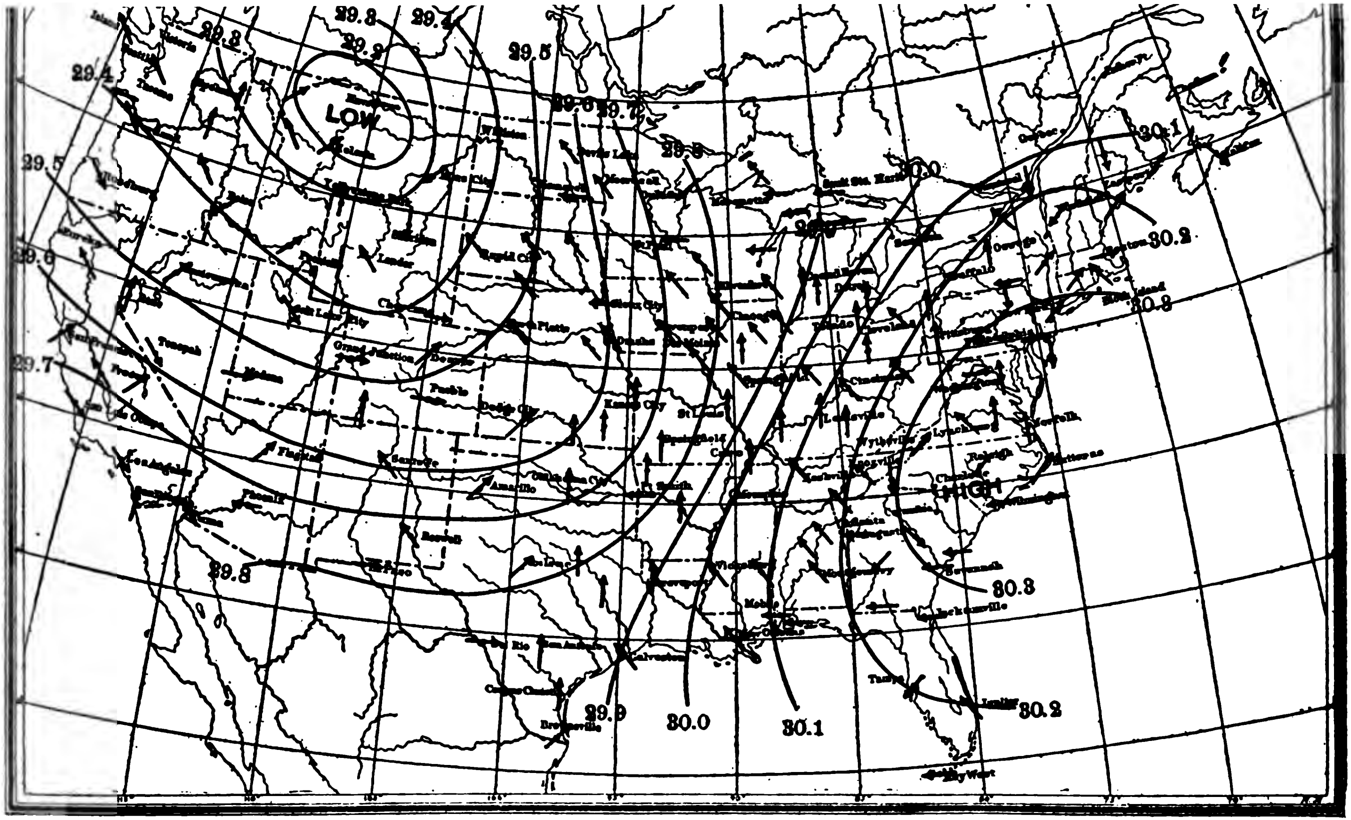


CHART A.—Arrows fly with the wind and show how the vaporous atmosphere of the Gulf of Mexico and the South Atlantic Ocean is drawn inland.

10,000 feet high skirting the Gulf and South Atlantic coasts. Of course this is impossible, but if nature had erected it there would be no question about floods in the Ohio and the Mississippi rivers and their tributaries, for there would be neither rivers nor tributaries; just as on the Pacific coast, the rain would fall on the ocean side of the mountains, and the world's greatest granary would be a barren waste.

Prof. Frank H. Bigelow, on page 17 of A Manual for Observers in Climatology and Evaporation, says:

> All this distribution of the general circulating currents, and the consequent precipitation, would occur whether there were forests or not growing on the land masses. It may be proper to say that the forests follow the precipitation and do not precede it.

There can be no question but that the action of the sun on the waters of the Gulf of Mexico and the adjacent ocean heavily charge the air with water vapor, and that this vaporous atmosphere is carried inland by the circulation of the air in such storms as are described in a preceding paragraph and illustrated on chart A, and that the effect is shown on chart B in the form of heavy precipitation in the region of the Gulf, which gradually shades away toward the Rocky Mountains.

It is therefore apparent that the precipitation that causes floods in the eastern half of the United States is from the aqueous vapor that is raised up from the vast waters to the south and southeast of our continent, and that *the supply is inexhaustible. Our rainfall, then, is the result of such fundamentally great causes as not to be appreciably affected by the planting or cutting away of forests, or by any of the operations of man in changing the character of the surface covering of the continent,* although to statistically and positively settle the question beyond the possibility of argument it would be necessary to have scientific data of temperature, rainfall, and the height of rivers, beginning at the first settlement of the continent and continuing through to the present time. Such records, of course, are not in existence. But the fundamental fact that the precipitation of the United States is due to the great hemispherical circulation of the air, and to the relation of the great bodies of water to land, and the direction of the vaporous-bearing currents, and the trend of mountain systems is something that can be positively shown.

Mr. Willis further says, in the same issue of Conservation, page 265, that:

> The mountains are wet because they are high, and they are heavily forested because they are wet. But there is also a reciprocal action of the forests on the wetness, for the radiation from the dark-green expanse is comparatively uniform and promotes frequent and steady rains. Were the mountains bare they would, like the bared sierras of Spain, receive occasional but violent downpours and send down excessive and disastrous floods, even more disastrous than now. * * * For in so far as we clothe the surface with green crops we lower the temperature of the rising air and favor precipitation on the verdure-covered plain.

It would be difficult to either confirm or disprove this statement of Mr. Willis. Certain it is that the rain is precipitated largely from air masses that exist at a considerable distance from the surface of the earth, and that the influence that Mr. Willis describes is in a thin stratum of air close to the earth. Rarely is this stratum saturated, even during the fall of rain. If, then, the processes that he describes do not bring the air to the saturation point, and if the

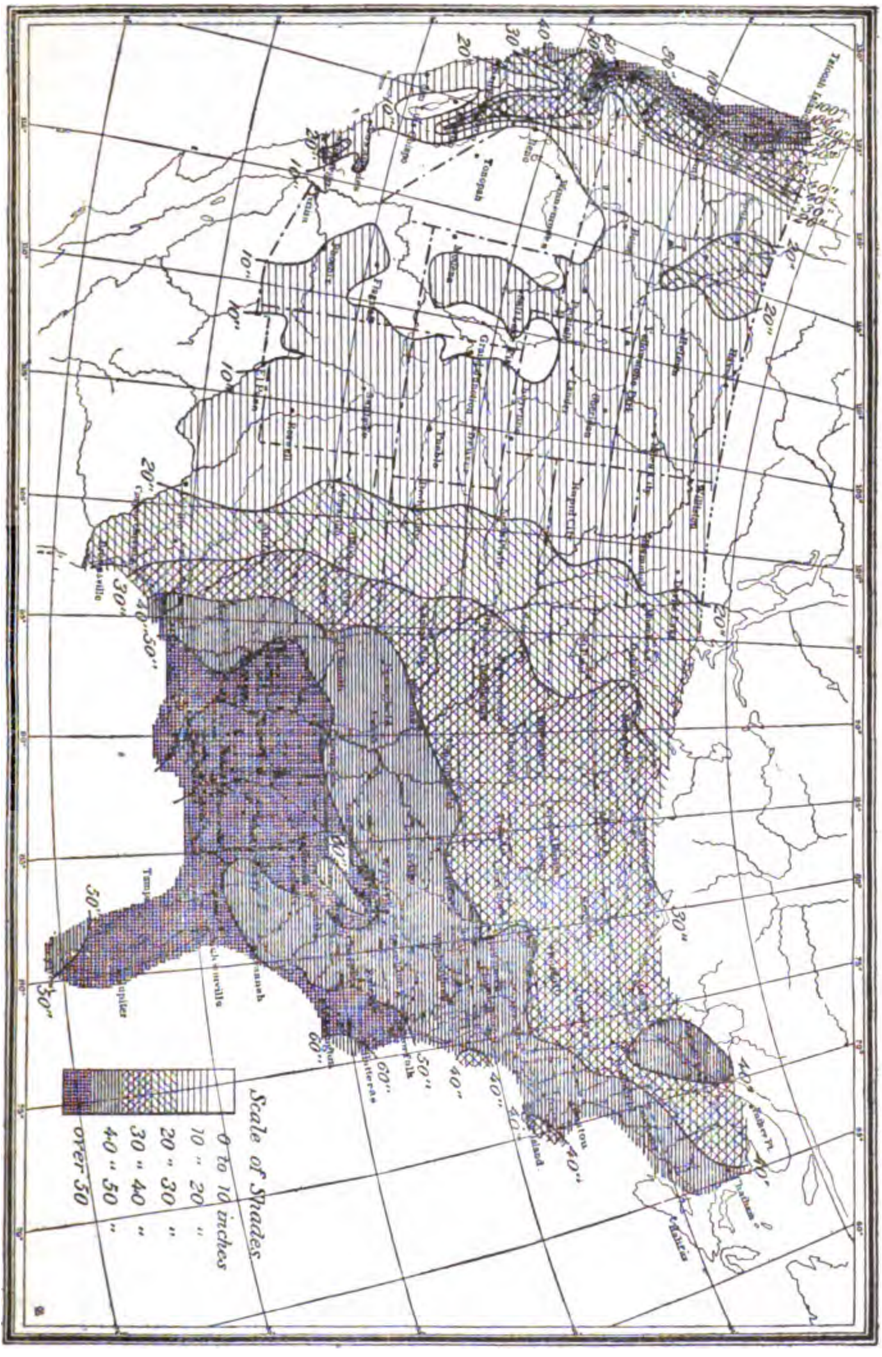


CHART B.—Annual precipitation.

precipitation occurs in the regions above those affected by these local surface conditions, I am unable to see how the rain can be either increased or decreased in its amount. Certain it is that most of the leading meteorologists of the world are of the opinion that the rainfall on continents is caused by the fundamentally great operations of nature as described above.

EROSION.

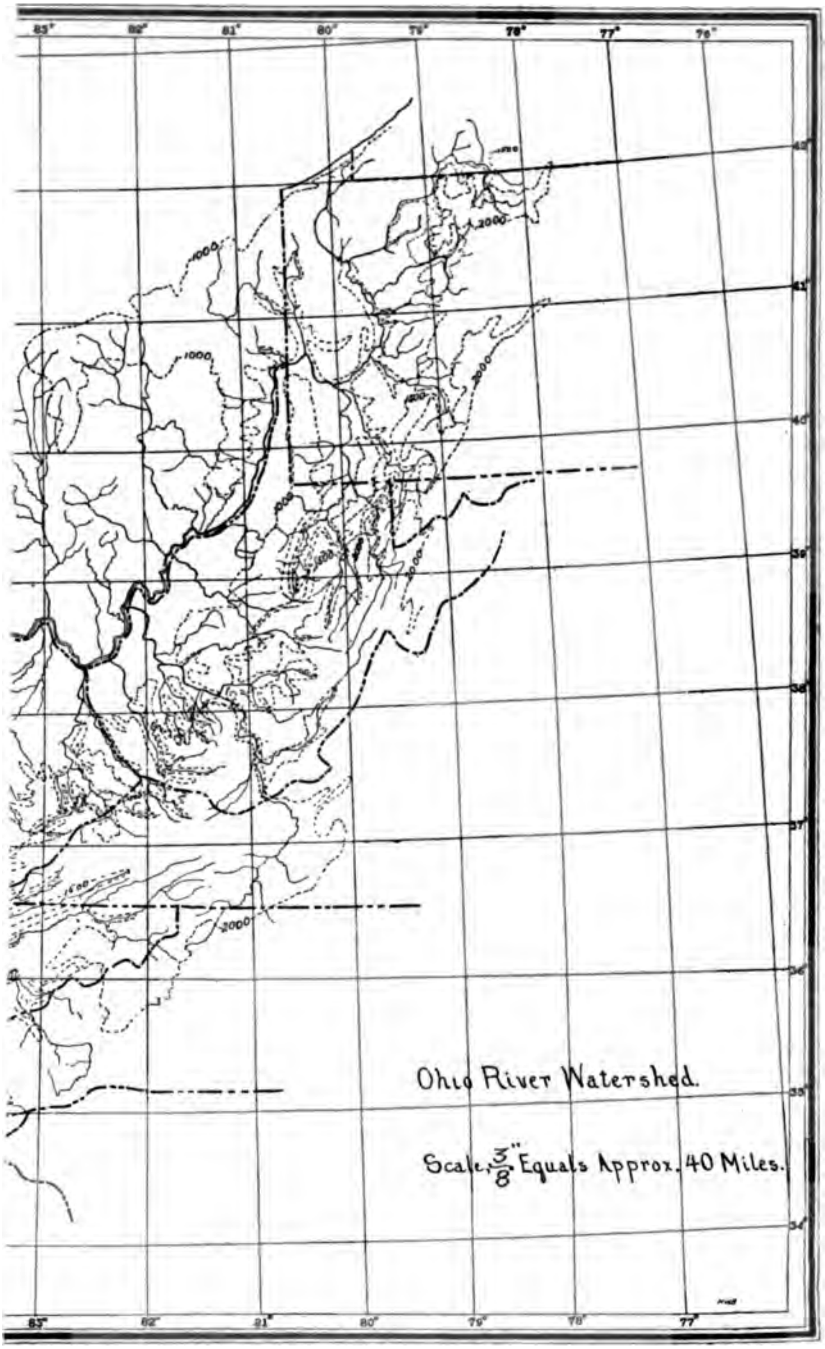
Another effect of deforestation, that of erosion, is of importance, but of unequal importance in different sections. In level countries it makes but little difference in this particular whether the ground is waste, cultivated, or densely forested, while in hilly or mountainous sections the result is different. When the soil becomes well sodded with grass, erosion is little worse in fields than in the woods, but usually the fields are cultivated from time to time, and occasions come when the best of care and cultivation can not prevent the formation of bad gullies that injure both the gullied fields and those of the lower grounds that are overflowed.

Of course, though, a field with an occasional wash yields more food material than the same area covered by a forest of any kind, so that only in exceptional cases—those in which erosion would probably be unavoidable and ruinous—is this a sufficient argument against clearing away the woods and the planting of crops in their stead, *for the time is come when we should not only increase the yield per acre by wise rotation of crops on cultivated ground, but clear up and seed to wheat, corn, grass, and fruits millions of acres that now lie idle under brush or forest.* In other words, every acre that will grow food for the people, and thereby reduce its cost and furnish sustenance for our increasing population and the teeming millions that are on the way to these shores, should be so employed; the remainder should grow timber that should be protected in its growth. Man and beast love the cooling shade, and the eye is pleased by the beauty of the wooded landscape. Therefore begin with the children and teach them to plant trees along the highways and byways and on the barren spots that will not produce food. Thus may we approach this problem rationally, with the object of gaining the greatest good for the greatest number for the longest period of time.

RATIO OF THE FORESTED AREA, OR MOUNTAIN WATERSHEDS, TO THE TOTAL WATERSHED.

I am of the opinion that not enough consideration has been given to the relative magnitude of the areas involved in the creation of floods. A flood in any given stream is usually caused by the precipitation over its entire watershed or over those of the major tributaries and is affected but comparatively little in a region like that of the Ohio basin by the precipitation over the extreme upper reaches, usually the forested area, or any other area that could be reforested without seriously encroaching upon the rich alluvial plains.

A critical examination of Chart C, which shows the entire river system of the Ohio basin and gives the exact limits of its boundaries, and which also indicates the elevations, shows what a comparatively small area in relation to the total catchment basin lies at



Ohio River Watershed.

Scale, $\frac{3}{8}$" Equals Approx. 40 Miles.

elevations of more than 1,000 or 1,500 feet above sea level. This chart furnishes a conclusive answer to those who believe that floods, except, of course, torrents in the mountain creeks, are caused by the precipitation on the comparatively small area of the watersheds at the headwaters of rivers. If it be granted that forests control the flow of streams, and I doubt that they do except as stated above, it will be necessary, in order to have an appreciable effect on navigable or other important rivers, to reforest areas many times in excess of anything that so far have been contemplated. *The rugged mountain slopes and tops, where land has little value, are unimportant as flood producers. It will be necessary actually to reforest the lower slopes and valleys where the land is of great value and where it should be devoted to agricultural purposes.* I can not escape this conclusion.

ARE FLOODS INCREASING?

Two papers have recently appeared, in both of which the argument is made that there is a marked tendency toward increasing flood frequency as a result of deforestation. The first of these papers in point of time was that of Mr. M. O. Leighton, Chief Hydrographer United States Geological Survey.[a] The second paper appeared in volume 2, Senate Document No. 676, beginning at page 112, and later as Forest Service Circular No. 176, January 11, 1910, under the signatures of Mr. William L. Hall, Assistant Forester, and Mr. Hu Maxwell, expert.

Before entering upon a discussion of these papers I wish to draw attention to the following statement in the last-named paper, page 3:

> * * * Both the Geological Survey and the Forest Service *have secured data*,[b] and the results warrant the statement that unmistakably floods are steadily on the increase in some of our most important rivers.

I wish to remark in connection with this statement that substantially all of the data used by the authors of the papers above mentioned were drawn from the records of the United States Weather Bureau.[c]

In Water-Supply Paper No. 234 the author has made a diagrammatic arrangement of data composed of annual and decennial means, whereby he shows an apparent progressive increase in the number of flood days at Wheeling, W. Va., and other points, without a proportionate increase in the amount of precipitation. It appears to me that his argument is defective in at least two particulars.

First. The flood or danger stage of the rivers at the various places discussed by him was long ago fixed by the Weather Bureau as being at the point where the river either overflows its banks or damages property adjacent thereto. Mr. Leighton has disregarded these points and arbitrarily assumed, for the purpose of his discussion, a considerably lower stage in each case, so that his argument fails completely so far as it relates to flood frequency; for example, at Wheeling, W. Va., he assumes a stage of 20 feet, whereas the Ohio at that point is not in flood until a stage of 36 feet is reached. What the author is discussing is therefore not floods as such, but moderate stages of the river.

---

[a] Report of National Conservation Commission, p. 95, and Water-Supply Paper No. 234.

[b] The italics are mine. (Author.)

[c] In Water-Supply Paper No. 234 the impression seems to be given that the author's researches and conclusions are based on a consideration of river discharge measurements. It is proper to state that river discharge measurements were begun under the direction of the United States Geological Survey in 1896 and that gauge readings of heights of rivers were begun by the United States Signal Service, now Weather Bureau, in 1874.

What appears to me to be a second defect in the author's argument lies in his acceptance of the total number of so-called flood days (20 feet or more being a day of flood) divided by the annual precipitation as an indication of flood intensity, since the annual rainfall, as he himself acknowledges,[a] bears little or no relation to floods. Greater floods may occur during a year of deficient precipitation than during one of excessive annual precipitation if the proper proportion of the rainfall be concentrated over a limited area in a limited time.

An examination of the data for Chattanooga, Tenn., given by that author, discloses the fact that there has not been any increase in the number of so-called flood days at that place. The average amount of precipitation for each daily river stage of 20 feet or more, as determined by him, is almost exactly the same for the two periods, 1884 to 1895 and 1896 to 1907, inclusive. But in the number of *actual flood days*, as determined by Professor Frankenfield, the official in charge of the Weather Bureau river and flood service, that is, 33 feet or over (and the river does not reach the danger or flood stage until it stands 33 feet above low water), there was a considerable decrease in the second period, in harmony with the precipitation.

I understand that when Mr. Leighton speaks of "the ratio of the annual number of days of flood to annual precipitation," he means the number of days (stage above 20 feet) in each year divided by the *total* precipitation for the year. Thus, if the number of flood days in any one year is 20, and the total precipitation is 40 inches, the ratio would be 20 divided by 40, or 0.5. These ratios are totaled in eleven-year periods and the average of each period obtained. The average for the first eleven years, as obtained by him, was 0.38, and of the second, 0.48, indicating, in his opinion, an increase in flood intensity during the second eleven-year period, as 1 inch of rain made only 0.38 of a flood during the first period, while in the second period 1 inch of rain made 0.48 of a flood. In other words, during the first eleven-year period 1 inch of rain made only 38 per cent of 20 feet of water, or 7.6 feet; while during the second period 1 inch of rain made 48 per cent of 20 feet of water, or 9.6 feet.

This line of reasoning leads to wrong conclusions, as it is certain that the ratios obtained by dividing the number of days that a certain gage reading was reached or maintained by the annual, or for that matter by any other, precipitation, without entering into the problem the exact height of water gives a meaningless result. It appears to me to be a fatal method of reasoning to take simply the number of days that a stage of 20 feet was reached, without regard to heights above 20 feet. Therefore, if on a certain number of days the gage reading was exactly 20 feet, one would get precisely the same quotient as he would if on the same number of days the gage readings were largely in excess of 20 feet.

---

[a] Page 22, Water-Supply Paper No. 234.

I now come to that part of the discussion in Water-Supply Paper No. 234 which has been widely quoted by the adherents of the forest-control idea, viz, the proposition that, although the flood periods in the Tennessee have decreased in later years due to diminished precipitation, the flood tendencies have increased. This idea, like others that have been put forward in this connection, is important if it can be substantiated; and if it is proven, then it is incumbent upon the author of that paper to show that the increase is due to deforestation, which he does not do. I have no data as to the area that has been cleared or that has been allowed to revert to forests, but it can not be great in twelve years.

This whole matter of the influence of forests upon climate and floods is so important to the nation in planning a correct economic policy for the future that we should move cautiously and be sure that we are building safely and wisely. I am heart and soul with the noble men and women who, as individuals or collectively, are striving to protect and conserve in the interests of the whole people the nation's resources of forest and field and of minerals and water power, and in this opinion I am generally and strongly sustained by the scientific staff of the Weather Bureau.

With regard to the matters of which this paper specifically treats I wish for the freest, fullest, and fairest discussion and investigation, with the end in view of correcting error if there be such and of finding common ground upon which all well-meaning persons may stand. Those whose official reports differ from mine I believe to be as honest and as sincere in their investigations and conclusions as I know myself to be.

To return to Supply Paper No. 234, referred to above, I quote as follows from page 23:

> The results for the Tennessee basin cover twenty-four years, from 1884 to 1907, inclusive. * * * Summing up the flood-producing rains for the twenty-four year period, it is found that the total is 335, of which 313 occurred from December to May, inclusive, and the remaining 22 during the other portion of the year. It is apparent that the number of such rains from June to November is not sufficient to afford a basis of comparison. Therefore only the December to May floods will be considered. * * * On dividing the period covered by these 313 floods equally, two consecutive twelve-year periods are afforded, which give a basis of comparison. The floods in the later period, resulting from a given depth of storm precipitation, are clearly shown to be more severe than in the earlier period. The method of presentation further makes it possible to compute the increase in flood tendency due to deforestation in the Tennessee.
>
> * * * * * * *
>
> If we now divide the number of flood days by the number of storms the result will be the number of days per storm.
>
> *Days of flood per storm.*

Period.	Storms in inches precipitated.							
	1 to 1.5.	1.5 to 2.	2 to 2.5.	2.5 to 3.	3 to 3.5.	3.5 to 4.	4 to 4.5.	4.5 to 5.
1884-1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896-1907	.4	.9	2.6	2.7	3.2	6	8	6.7
Percentage increase	− 43	80	4	50	22	20	33	− 17

> The algebraic sum of the above percentages is 149 and the average is 18.75, which sums up the effects of deforestation on run-off from 1884 to 1907, inclusive.

I invite attention to the figures given in this table "Days of flood per storm." If the run-off in the second period was greater than in the first, due to deforestation, would not the latter show a uniform and progressive influence increasing as the amount of rainfall increased? How, then, does it happen that a decrease in run-off of 43 per cent is shown for rains of intensity 1 inch to 1.5 inches, while in the next higher grade of intensity, viz, 1.5 to 2 inches, an increase of 80 per cent is shown? In the next higher grade, viz, 2 to 2.5 inches, the increase drops to 4 per cent. These results founded, in my judgment, on incorrect premises, are both inconsistent and meaningless. To "divide the number of flood days by the number of storms" gives no valuable quotient, for the gage readings selected as floods are not floods, but only moderate stages, and no account is taken of the actual height of the water, and while the conclusion is reached that there is an increase in flood intensity of 18.75 per cent in the Tennessee basin in the past twelve years due to deforestation, no records or other evidence are presented that there is not as much forest area in this basin as there was twelve years ago; or that, if there is a decrease, it would be sufficient to account for such a large increase in flood intensity.

But—and here is the most important matter in the consideration of Mr. Leighton's conclusions—no matter how complete the data may be, or how fundamentally sound and fair its collation and grouping, the comparison, the one with the other, of such short periods as those measured by only twelve years, can not give results with regard to changes in climate and floods that will permit the most skilled meteorologist or engineer to draw fundamental conclusions that can have any value. Precisely the same amount of rain falling in the two periods and no change whatever in forest or cultivated area might produce largely differing results on floods, depending on the sequence with which it fell over the different tributaries and how it was concentrated or scattered, and on many other complicated conditions of run-off, such as the coinciding of the flood volume from one tributary with that of another, instead of each passing down the main stream at different times.

There is also the difficulty of securing accurate precipitation data. Whenever the height of the gage is altered or other change made in its environment that disturbs the flow of the air currents the readings of one period may not fairly be compared the one with the other. These defects vitiate the precipitation data of many stations of the Weather Bureau, especially those in large and growing cities, and can only be remedied by the Government controlling for a long period of years an area at each station so large that it can determine the exposure and keep it constant.

Another way of comparing the precipitation and the river stages of the Tennessee basins.—I give in the following table the rainfall at Chattanooga and Knoxville separately for the months December to May, inclusive, for each of the twenty-four years considered in Water-Supply Paper No. 234; also the total number of days of river stages of 20 feet and above on the Chattanooga gage. The rainfall so tabulated includes only the heavy rains, and the arrangement according to intensity is precisely the same as that followed in Water-Supply Paper No. 234.

Heavy rains at Chattanooga and Knoxville, Tenn., during six months of each year (December, 1883, to May, 1907).

December-May, 1883-1907.	1 to 1.5 inches.		1.5 to 2 inches.		2 to 2.5 inches.		2.5 to 3 inches.	
	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.
First half:								
Chattanooga	57	68.65	16	27.54	8	17.83	13	35.67
Knoxville	44	51.01	26	45.59	13	29.44	4	11.04
Total	101	119.66	42	73.13	21	47.27	17	46.71
Mean								
Second half:								
Chattanooga	52	62.48	11	18.18	12	26.28	9	24.13
Knoxville	48	55.87	21	35.47	10	22.19	10	27.48
Total	100	118.35	32	53.65	22	48.47	19	51.61
Mean								

December-May, 1883-1907.	3 to 3.5 inches.		3.5 to 4 inches.		4 to 4.5 inches.		4.5 + inches.		Grand total.
	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	
First half:									
Chattanooga	4	13.45	4	15.07	2	8.58	6	33.43	220.22
Knoxville	4	12.70	1	3.78	2	8.79	4	22.04	184.39
Total	8	26.15	5	18.85	4	17.37	10	55.47	404.61
Mean									202.30
Second half:									
Chattanooga	4	13.41	2	7.71	2	8.38	4	23.27	183.84
Knoxville	5	16.17	2	7.46					164.64
Total	9	29.58	4	15.17	2	8.38	4	23.27	348.48
Mean									174.24

The data of the above table have been divided into two periods of twelve years each, with the following results:

First period.

Total number of heavy rains at Chattanooga	110
Total number of heavy rains at Knoxville	100
Total	210

Total amount of the above heavy rains as per table, 404.61 inches.

Dividing this total by two, to get the approximate average of the heavy rains for the watershed, we get 202.30 inches.

Total number of days with stages of 20 feet or more at Chattanooga	166

Dividing the amount of the heavy rains in the watershed by the number of days with a river stage of 20 feet or over, we get $\frac{202.30}{166}=1.220$ inches as the amount of rainfall that probably produced one day of a stage of water in the river of 20 feet or more.

Second period.

Total number of heavy rains at Chattanooga	96
Total number of heavy rains at Knoxville	96
Total	192

Total amount of the above heavy rains, 348.48 inches.

Dividing this total as before, we get as an approximate average of the heavy rains in the watershed 174.24 inches.

Total number of days with stages of 20 feet or over in the river	141

Dividing as before, we get as the probable amount of rainfall in the second period required to produce a day of 20 feet or over in the river, 1.236 inches, as against 1.220 inches in the first period.

The difference between the line of reasoning employed in getting the above results and those given in Water-Supply Paper No. 234 is that the author of the latter attempts to differentiate between the stages produced by rains of varying intensity and to assign to such rains a given number of so-called "flood days," while in this paper the assertion is made that in the first period there were a given number of days with a stage of 20 feet and over in the river, and that during that time the heavy or flood-producing rains amounted to so much. Dividing, then, the total of the flood-producing rains by the corresponding number of days with a stage of 20 feet or over, the results given above are reached, viz, that for the first period it took 1.22 inches of rainfall to produce a day with a 20-foot stage in the river. These figures contradict the contention that an equal depth of rain in the last period as compared with the first produced more severe floods in the river. I only present them to show how easy it is to arrange data so as to prove both sides to a question. While this line of inquiry is open to less objection than that followed by Leighton, it does conform to the plan of the latter in so far as it uses the number of days that the river stood at or above 20 feet, instead of taking into consideration the actual height of the water. The most that can be said is that this form of inquiry shows no increase in flood intensity.

Rainfall and run-off of the Ohio Basin.—We now come to a different and more reliable form of investigating this question of the relation of precipitation to run-off.

We have no direct method of measuring the run-off, but we can reach a fair approximation to it by a comparison of the rainfall and river data for any given watershed. If, for example, the surface conditions over any considerable part of a watershed have been materially changed by deforestation or other means, and if, as claimed, such change operates to increase the run-off, then the flow of water in the streams after the change has been brought about should be greater for equal depth of precipitation. This method is a rough one, to be sure, but it appears to be the only one permitted by the records as they exist.

Cincinnati, Ohio, has been chosen as the point whose river observations are best adapted to our purpose, although some objection to that place lies in the constriction of the natural river channel caused by the encroachment on the banks of the stream by various artificial structures. The station at Pittsburg, Pa., is better situated for comparative purposes, but the low-water stages at that place of late years have been vitiated by the construction of the Davis Island dam. The construction of dams at several places in other rivers has lowered the value of low river gauge readings for comparative purposes.

In the tables which follow I have given the actual mean monthly stage of the Ohio at Cincinnati for every month of the period 1871 to 1908. The average of these monthly means has been computed for the first period of nineteen years; these averages have been summed up for the twelve months of the year, and that sum has been divided by twelve in order to get the annual mean. The number so obtained, 17.3 feet, is therefore the average stage of the river for the entire nineteen years, as computed from all of the daily stages for that period. In like manner the average stage of the river for the second period of years has been computed and is given in the following table:

Mean monthly and annual river stages in the Ohio River at Cincinnati, Ohio, for the period 1871–1908.

[In feet and tenths.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1871	14.6	23.1	25.3	16.5	21.8	8.2	7.1	5.1	5.4	3.2	6.5	7.3	
1872	14.0	14.1	13.3	25.8	11.8	10.9	11.9	8.4	5.1	4.2	10.0	10.5	
1873	22.6	29.4	21.4	29.2	25.6	9.2	13.3	10.0	6.6	7.3	15.6	28.6	
1874	29.7	27.9	25.7	31.6	20.7	7.8	6.1	9.0	4.2	5.4	4.6	13.4	
1875	18.3	16.7	34.4	23.9	14.7	11.8	25.0	26.7	5.1	7.4	15.9	24.3	
1876	31.4	33.9	25.6	25.4	18.2	10.1	11.8	10.6	16.8	10.7	11.7	12.1	
1877	28.1	18.4	28.0	23.1	17.4	12.1	11.3	5.5	6.2	5.1	12.1	15.1	
1878	20.0	24.2	24.2	14.5	22.0	12.5	9.0	10.6	13.7	6.0	14.8	29.1	
1879	23.2	26.6	32.8	22.9	11.4	7.1	5.6	9.9	6.9	3.2	5.4	19.2	
1880	29.2	28.3	35.2	24.6	15.8	14.0	9.4	8.4	7.0	4.6	10.4	18.1	
1881	20.7	33.1	27.2	29.4	16.1	16.5	7.8	4.9	3.6	4.4	14.8	25.0	
1882	42.0	44.0	34.2	18.2	30.6	26.5	16.9	13.7	13.9	9.0	8.7	12.7	
1883	18.1	48.6	20.3	36.0	49.0	61.5	12.9	8.7	4.4	7.9	38.0	32.2	
1884	24.5	54.4	36.5	24.5	17.5	11.3	8.5	6.5	3.6	3.9	4.4	12.2	
1885	25.6	15.6	17.1	26.5	15.0	14.7	6.8	12.5	11.0	8.5	15.5	18.1	
1886	24.7	26.0	20.6	37.4	22.0	15.5	13.8	10.0	5.4	5.2	12.2	19.4	
1887	20.4	48.4	29.4	24.0	20.6	14.8	5.7	4.9	3.3	3.3	3.6	6.1	
1888	20.2	20.1	23.0	23.8	13.8	10.4	14.6	12.1	16.4	17.9	27.4	16.2	
1889	25.2	24.1	20.9	19.0	16.0	25.2	18.5	12.2	6.7	8.0	24.6	23.9	
1890	33.0	37.9	46.0	31.7	32.5	19.8	10.8	9.7	20.8	21.2	24.2	17.3	
1891	31.8	46.8	37.2	30.6	9.8	18.9	13.0	11.2	9.7	4.9	9.6	18.9	
1892	23.8	24.5	25.4	31.5	25.2	23.1	11.6	7.7	5.7	4.3	6.4	11.1	
1893	12.7	41.1	25.8	26.8	36.1	14.9	8.3	4.8	7.2	10.5	9.5	16.5	
1894	17.3	27.2	22.6	19.1	16.9	12.3	5.6	4.3	4.8	4.6	6.6	12.0	
1895	28.3	13.9	27.4	24.4	12.3	6.5	7.5	6.1	4.9	3.0	3.4	9.4	
1896	14.1	23.6	22.5	26.1	12.3	11.7	22.1	20.1	6.7	14.8	13.8	19.7	
1897	14.4	36.3	40.3	26.3	23.1	12.8	13.9	10.3	4.8	3.5	8.0	17.8	
1898	35.3	25.0	31.3	27.1	23.7	11.7	8.6	20.2	7.7	10.1	17.1	18.7	
1899	31.8	25.9	40.1	26.7	17.4	13.6	8.4	8.0	5.1	3.9	6.4	13.4	
1900	18.7	24.5	28.9	17.8	11.2	10.8	9.5	7.9	5.0	4.3	10.3	19.2	
1901	15.8	13.8	22.2	39.5	25.5	28.1	13.1	9.6	10.9	6.4	5.6	20.6	
1902	19.9	19.2	37.2	26.7	13.6	11.0	19.4	9.9	4.4	7.6	6.3	26.9	
1903	23.1	39.7	42.5	32.9	12.0	13.5	12.7	6.7	8.2	6.6	7.3	9.6	
1904	19.4	20.3	34.6	26.6	20.1	16.2	13.5	6.3	5.0	3.8	4.2	4.6	
1905	14.9	21.4	33.3	19.7	25.2	16.3	15.8	12.9	10.2	10.8	12.0	25.6	
1906	26.8	13.9	26.3	30.3	14.3	12.5	10.1	14.4	10.1	13.3	15.8	23.3	
1907	45.7	22.0	40.1	23.9	22.5	27.2	18.3	13.5	12.1	10.6	17.0	19.4	
1908	22.0	32.2	41.9	35.8	30.8	12.9	10.0	8.6	4.4	3.6	4.8	5.2	
Mean:													
1871–1889	23.8	29.3	26.1	25.1	20.0	15.8	11.4	10.0	7.6	6.6	13.5	18.1	17.3
1890–1908	23.6	26.8	32.9	27.6	20.2	15.5	12.2	10.1	7.8	7.8	9.9	16.3	17.6
1871–1908	23.7	28.1	29.5	26.3	20.1	15.6	11.8	10.0	7.7	7.2	11.7	17.2	17.4

The average precipitation for the watershed has not been so easily obtained. Only in exceptional cases are continuous measurements of precipitation available for comparative studies. The government records in large cities are of necessity made from gauges whose immediate environment has been changed repeatedly in the course of a long series of years, and it was for this reason that the rain-gauge records from Cincinnati and Pittsburg were ignored. The points selected—viz, North Lewisburg and Portsmouth, Ohio, and Confluence and Franklin, Pa.—are the best and practically the only long-period records available in this watershed. A better distribution throughout the watershed would have been preferred, but it is not possible to obtain it. The precipitation, like the river stages, has been computed in periods of nineteen years each. The tables follow:

Annual precipitation in the Ohio watershed for the period 1871 to 1908, inclusive.

[In inches and tenths.]

Year.	North Lewisburg, Ohio.	Portsmouth, Ohio.	Confluence, Pa.	Franklin, Pa.	For the watershed.
1871	30.6	30.7	[a]27.7	34.7	....
1872	28.6	31.1	[a]31.0	41.5	....
1873	37.2	46.2	[a]41.4	54.9	....
1874	34.0	38.3	[a]39.4	47.4	....
1875	43.2	45.7	39.1	45.8	....
1876	42.0	41.2	46.4	46.9	....
1877	37.3	35.0	45.0	43.5	....
1878	44.0	29.9	41.1	40.1	....
1879	48.4	35.6	38.8	37.7	....
1880	46.4	49.0	49.2	34.0	....
1881	44.0	40.8	41.4	39.1	....
1882	45.8	56.2	55.1	45.8	....
1883	48.9	48.5	49.8	41.3	....
1884	34.3	42.3	42.1	42.0	....
1885	38.8	37.3	39.3	44.6	....
1886	40.6	45.3	44.1	38.8	....
1887	35.0	40.7	[b]31.2	40.8	....
1888	47.6	48.3	[b]47.3	49.2	....
1889	30.8	39.3	40.0	43.8	....
1890	45.2	57.6	60.1	58.5	....
1891	44.2	42.8	57.5	[c]51.4	....
1892	40.2	44.1	38.4	[c]47.6	....
1893	49.1	37.9	43.4	[c]48.7	....
1894	39.6	36.2	42.1	[c]43.3	....
1895	29.0	31.2	35.1	[c]33.5	....
1896	48.3	39.9	50.2	[c]41.2	....
1897	43.5	49.1	45.8	39.6	....
1898	52.2	48.1	53.2	39.1	....
1899	34.0	42.9	48.9	32.8	....
1900	32.5	34.6	44.0	31.7	....
1901	29.6	39.7	41.2	42.2	....
1902	36.6	37.2	45.9	39.1	....
1903	28.7	37.3	38.3	45.6	....
1904	35.4	29.2	31.4	40.8	....
1905	[d]35.1	43.3	51.1	45.1	....
1906	[d]33.7	44.4	48.7	[e]40.2	....
1907	[d]37.6	42.3	55.8	[e]42.3	....
1908	30.1	40.0	42.1	[e]41.1	....
Mean:					
1871–1889	39.8	41.1	41.5	42.7	41.3
1890–1908	38.1	40.9	46.0	42.3	41.8
Mean for entire period	39.0	41.0	43.8	42.5	41.6

[a] Record of Pittsburg, Pa.
[b] Record of Lock No. 4, Pennsylvania.
[c] Record of Warren, Pa.
[d] Record of Columbus, Ohio.
[e] Record of Parkers, Pa.

Summarizing the above, we have:

Average stage of the Ohio River at Cincinnati, Ohio:	Feet.
1871 to 1889	17.3
1890 to 1908	17.5
Average precipitation in the Ohio watershed, as determined from the stations above named:	Inches.
1871 to 1889	41.3
1890 to 1908	41.8

I consider that the results secured from the discussion of the precipitation and the gauge readings in the Ohio basin, as given in the foregoing tables, form one of the most important contributions made by this paper. Here we have avoided the using of indefinite and meaningless data, and have taken the longest period of time for which accurate records can be secured on a watershed that is suitable for this line of inquiry. We have not simply counted the number of days that the river stood above some arbitrarily selected stage without taking into consideration the exact height of the river. Neither have we divided the gauge readings by some arbitrarily selected portion of precipitation data. On the contrary, we have endeavored to profit by the errors of previous investigations, and to lay the foundation of an inquiry that would mean something when we reached the end of our computations. For this reason we have selected a typical station on the main stream that drains the Ohio Basin and have discussed rainfall data that are the most accurate of any in the region, having been subject to less errors due to varying environments. Any deductions made from an inquiry founded with less care, or from data of a less degree of accuracy, must bring results from which it would be unsafe to form definite conclusions.

Now let us see what is the result. The average stage of the river for the first nineteen years is 17.3 feet, and for the last nineteen years 17.5 feet, showing that there is practically no change in the run-off of the Ohio Basin between the first period and the last. When we examine the average precipitation over the watershed that is drained by this river we find that for the first nineteen years it was 41.3 inches, and for the last nineteen-year period it was 41.8 inches, a slight increase in precipitation for the latter period that agrees precisely with the slightly greater average flow of water. There is a perfect agreement here between the precipitation and the flow of the stream. I do not know what has been the area deforested in this valley during the thirty-eight years under discussion, but whatever it is it seems to be apparent that such altering of the relation of forest area to cultivated area has had no appreciable effect on the flow of the Ohio River. I am aware of the fact that by the studying of short periods of data on small tributary streams, and especially by the grouping of data dissimilar from what is employed in this discussion, all manner of results may be shown.

I believe that the reader will acknowledge that I have shown in the several preceding paragraphs that the average discharge of the Ohio River, where I presume deforestation has been as great as in any other part of the country during recent time, has not changed for a period of thirty-eight years, except as caused by precipitation. It will now be interesting to know how the two periods compare with regard to extremely high water and extremely low water, and this will be discussed in the coming pages.

High water and low water on the rivers of the Ohio basin.—I had Prof. H. C. Frankenfield, Chief of the River and Flood Division of the Weather Bureau, compile the data from one station on the Cumberland, three on the Tennessee, and five on the Ohio, and establish the average high water for the four wet months, January to April, and the average low water for the four dry months, July to October. He then took the departure from the normal, both for the precipitation and for the height of the rivers, and found that *the average high water was no higher and the average low water was no lower for the last half of the period than for the first half.* The differences were so slight as to be inappreciable, but what changes occurred were in favor of the low water being slightly higher and the flood waters slightly less. There were variations in the periods and intensities of floods that bear a direct and proper relation to the precipitation. In making his report, Professor Frankenfield points to the fact that the low-water stages at Pittsburg, Pa., and Nashville, Tenn., are not fairly comparable with those of the other stations on account of permanent pool stages caused by dams operated during the low-water season for purposes of navigation. The first dam below Pittsburg was placed in operation in 1885, and that at Nashville in 1904. The effect of these dams is to furnish higher low-water stages than would result without them. The effect upon the normal low-water stage at Nashville was not marked, but at Pittsburg it was perceptible. However, in his conclusions he did not make allowance for the slightly higher low-water stages at Pittsburg on account of the dam, but when included with the other stages of the river this defect probably is not apparent.

According to our line of reasoning, which we believe to be fair and conservative, it is shown that the average discharge of the Ohio River is not greater as the result of deforestation during the last nineteen years than during the preceding like period, and that the average high water in the rivers of the entire basin, which includes the Tennessee, the Cumberland, and the Ohio, is not higher and the low water is not lower.

Are real flood stages more numerous than formerly?—The next line of inquiry will be for the purpose of determining whether or not there has been in recent time an increase in the number of days that these rivers were at or above the flood stage, and in making this inquiry *exact flood stages* will be used, not simply gauge readings less than flood. Again I called on Professor Frankenfield to prepare the necessary data. As the data was not complete with regard to flood stages for the first ten years of the period that we have been discussing, he took a period of ten years less in length, beginning with 1879, and as the result of his computations we have the following table:

Number of days in each year that the rivers were at or above the flood stage.

[Flood stage given with name of station.]

	Cumberland River, Nashville, Tenn.	Tennessee River.			Ohio River.					Total.
		Chattanooga, Tenn.	Florence, Ala.	Johnsonville, Tenn.	Pittsburg, Pa.	Cincinnati, Ohio.	Louisville, Ky.	Evansville, Ind.	Cairo, Ill.	
Flood stage in feet	40	33	16	21	22	50	28	35	45	
Year.										
1879	3	3	10	[a] 19	......	......	......	4	......	......
1880	19	4	19	[a] 51	......	4	4	31	......	......
1881	......	......	4	([b])	3	2	......	11	6	......
1882	30	9	44	80	......	9	8	63	56	......
1883	6	4	15	[a] 73	2	16	15	[a] 34	21	......
1884	25	12	42	[a] 91	3	19	19	51	40	......
1885	......	......	10	20	1	......	......	5	......	......
1886	14	11	17	31	1	12	11	19	21	......
1887	11	......	10	44	......	13	11	53	32	......
1888	......	......	13	27	......	......	......	3	5	......
1889	......	......	8	12	......	......	......	......	......	......
1890	14	5	16	55	2	14	17	65	39	......
1891	15	9	35	63	4	8	6	67	13	......
1892	......	5	18	40	1	......	......	8	30	......
1893	3	1	17	44	2	10	2	28	18	......
1894	3	......	2	14	1	......	......	......	......	......
1895	......	......	4	15	1	......	......	3	......	......
1896	6	4	7	18	......	......	......	6	......	......
1897	16	9	29	48	2	8	7	36	48	......
1898	......	......	......	20	3	15	15	37	17	......
1899	2	13	26	66	1	9	5	39	26	......
1900	......	......	4	18	1	......	......	......	......	......
1901	......	1	17	42	3	9	7	12	......	......
1902	12	6	30	50	3	4	......	26	......	......
1903	1	......	31	58	3	8	1	45	25	......
1904	......	......	3	9	4	......	......	19	15	......
1905	......	......	3	13	5	......	......	4	......	......
1906	......	1	......	22	......	1	......	11	12	......
1907	......	......	......	24	4	22	22	46	23	......
1908	......	......	3	18	3	12	5	57	11	......
Total, 1879–1893	140	63	278	650	19	107	93	442	281	2,073
Total, 1894–1908	40	34	159	435	34	88	62	341	177	1,370
Grand total	180	97	437	1,085	53	195	155	783	458	3,443

[a] Data incomplete.

[b] Data missing for this year.

	Days.
Total 1879-1893	2,073
Total 1894-1908	1,370
Excess of first period over second period	703
Average per year, 1879-1893	138.2
Average per year, 1894-1908	91.3
Excess per year first period over second period	46.9

From the foregoing it will be seen that in the first fourteen years there were 2,073 days that the Cumberland River at Nashville; the Ohio at Pittsburg, Cincinnati, Louisville, Evansville, and Cairo; the Tennessee at Chattanooga, Florence, and Johnsonville, were at the flood stage—that is, they were bank full or overflowing. During the last fourteen years the number of such days is 1,370, an excess in the first fourteen years of 703 days, or an average of 46.9 days excess per year in the first period over the second.

Now, I would guard against unsafe conclusions from these results. The fact is that abnormally heavy precipitation for several years in the forepart of the first fourteen-year period, especially that which caused the famous 1882 flood, places such a preponderance of flood days in the first period that it would be unfair to claim that there has been any such permanent decrease in flood intensity as is shown by this table. It is given for what it is worth, and further to emphasize the fact that conclusions on which fundamental theories or policies are based should not be founded upon short-period data. While I am strongly of the opinion that there is no permanent increase in the number of flood days for the rivers of the United States as a whole, between the last fifty years and the preceding fifty years, I should not rely upon such short-period data as is contained in this table to sustain my belief. But if these data of twenty-eight years, which shows such a marked decrease in flood intensity of the rivers of the Ohio Valley, and which are founded upon unquestionably accurate data, are not sufficient evidence for a scientific man to claim statistical proof of the decrease of floods, what shall one say of the statements made by Messrs. Hall and Maxwell, of the Forest Service, in volume 2, Senate Document No. 676, in a paper on "Surface conditions and stream flow," which begins at page 112, as follows:

THE TENDENCY IS TOWARD INCREASED FLOODS.

On the Potomac River, for which measurements are given for eighteen years, the number of floods during the first half of the period was 19; during the second half, 26; while the number of days of flood in the first half was 33, and in the second half, 57.

On the Monongahela River measurements are given for twenty-two years. During the first half of the period there were 30 floods; during the second half, 52. The number of days of flood during the first half of the period was 55; during the second half, 100.

On the Ohio River measurements are given for twenty-six years. During the first half of the period there were 46 floods; during the second half, 59. The number of days of flood during the first half was 143, during the second half, 188.

On the Cumberland River measurements were given for eighteen years. During the first half of the period there were 32 floods; during the second half, 43. The number of days of flood during the first half was 89; during the second half, 102.

On the Wateree River measurements have gone on for sixteen years. In the first half of the period the number of floods was 46; in the second half, 70. The number of days of flood in the first half of the period was 147; in the last half, 187.

On the Savannah River measurements have continued for eighteen years. During the first half of the period the number of floods was 47; during the second half, 58. The number of days of flood during the first period was 116; during the second half, 170.

On the Allegheny River measurements are given for thirty-four years. During the first half of the period there were 39 floods, during the second half, 53. The number of days of flood during the first half was 92; during the second half, 131.

On the Tennessee River measurements have been taken for thirty-four years. During the first half of the period there were 32 floods, during the second half, 33. The number of days of flood during the first half was 173, during the second half (in this case there was a falling-off), 137.

The conclusions arrived at by the authors are, in my judgment, faulty, because:

First. The shortness of the period of observations at the majority of the stations discussed.

Second. The arbitrary assumption as flood stages of certain heights of water much below that necessary to cause a flood.

As to the period of observations: Those of us who are accustomed to the computation of normals or mean values have always realized how little value they possess unless obtained from data covering a long period of years. This is true of temperature normals, which vary but little from year to year. How much more must it be true of precipitation and river-stage data, with their wide extremes and irregular fluctuations? As a matter of fact any average of river conditions, or any mean annual precipitation determined from ten or fifteen years' observations, would be of little or no value in a discussion of this character, and when two of these short-period normals are compared with each other the actual errors would probably be multiplied.

Second, opinions may differ, of course, as to what constitutes a flood, but the Weather Bureau (and engineers generally) have uniformly defined a river to be in flood when it reached a stage above which damage would be caused, practically the bank-full stage. This being so, it would appear reasonable and proper that this definition of the term should be accepted and data discussed accordingly. If the flood stage at a given point is 18 feet, an assumption of a lower or a higher figure for purposes of investigating the frequency of floods must necessarily be misleading.

I will now take up the rivers in the order named in the quotation and give the net result of Professor Frankenfield's inquiry as to the number of *real* floods:

Potomac.—On the Potomac River the number of floods has not increased, but there were more days of a 12-foot stage in the last period than in the first. The explanation of this increase is found in the precipitation.

Monongahela.—On the Monongahela River, using data for Lock No. 4, Pennsylvania, 40 miles above Pittsburg, there were two more floods in the second period as compared with the first, the figures being 13 and 11, respectively. Two of the days of flood occurred in March, 1907, as a result of abnormal weather conditions over the watershed.

Ohio at Wheeling.—There was an increase in the number of floods at Wheeling, but said increase is not shown farther down the river than Parkersburg. It (the increase) disappeared below the mouth of the Great Kanawha, as indicated by the Cincinnati records. The reason ascribed for this increase in flood frequency is an increase in short-period heavy rains. The same conditions appear to have obtained in the Allegheny at Freeport.

Cumberland.—There has been no increase in flood conditions in the Cumberland.

Wateree.—There was a marked increase in the number of flood days on this river during the second period. On the other hand, the precipitation in the watershed shows a like marked increase.

Savannah.—The record for the Savannah River at Augusta shows a marked decrease in the second period as compared with the first.

Allegheny at Freeport.—See Wheeling.

Tennessee.—See detailed discussion on this river in another part of this paper.

CONCLUSIONS.

(1) Any marked climatic changes that may have taken place are of wide extent and not local, are appreciable only when measured in geologic periods, and evidence is strong that the cutting away of the forests has had nothing to do with the creating or the augmenting of droughts in any part of the world.

(2) Precipitation controls forestation, but forestation has little or no effect upon precipitation.

(3) Any local modification of temperature and humidity caused by the presence or absence of forest covering, the buildings of villages and cities, etc., could not extend upward more than a few hundred feet, and in this stratum of air saturation rarely occurs, even during rainfall, whereas precipitation is the result of conditions that exist at such altitudes as not to be controlled or affected by the small thermal irregularities of the surface air.

(4) During the period of accurate observations, the amount of precipitation has not increased or decreased to an extent worthy of consideration.

(5) Floods are caused by excessive precipitation, and the source of the precipitation over the central and eastern portions of the United States is the vapor borne by the warm southerly winds from the Gulf of Mexico and the adjacent ocean into the interior of the country, but little from the Pacific Ocean crossing the Rocky Mountains.

(6) Compared with the total area of a given watershed, that of the headwaters is usually small and, except locally in mountain streams, their run-off would not be sufficient to cause floods, even if deforestation allowed a greater and quicker run-off. Granting for the sake of argument that deforestation might be responsible for general floods over a watershed, it would be necessary, in order to prevent them, to reforest the lower levels with their vastly greater areas, an impossibility unless valuable agricultural lands are to be abandoned as food-producing areas.

(7) The run-off of our rivers is not materially affected by any other factor than the precipitation.

(8) The high waters are not higher, and the low waters are not lower than formerly. In fact, there appears to be a tendency in late years toward a slightly better low-water flow in summer.

(9) Floods are not of greater frequency and longer duration than formerly.

○

Walter Mulford

THE RELATION OF FORESTS TO STREAM FLOW.

BY

JAMES W. TOUMEY,
Collaborator, Bureau of Forestry.

[Reprint from Yearbook of Department of Agriculture for 1903.]

CONTENTS.

Page.
Introduction 279
What causes rainfall 280
What becomes of the rainfall 280
Do forests influence evaporation? 281
Do forests influence transpiration? 283
The influence of forests in regulating the run-off 283
Comparison of run-off from forested and nonforested areas 285
Do forests increase the run-off? 287
Conclusion 288

THE RELATION OF FORESTS TO STREAM FLOW.

By James W. Toumey,
Collaborator, Bureau of Forestry.

INTRODUCTION.

For the purposes of the present discussion "forest" must be understood to mean a growth of trees sufficiently dense to form a fairly unbroken canopy of tops, not a scattered growth of low, round-headed trees with bushes and herbage constituting the dominant types of vegetation.

Forests of this kind do not occur in the United States where the mean annual precipitation falls below 18 to 20 inches, except on restricted areas where unusual conditions prevail. The line of separation between the great eastern forest area and the plains approximately coincides with a north and south line marking a mean annual rainfall of 20 inches. The streams which rise in the Rocky Mountains and flow eastward are bordered by forests for long distances into the plains, where the annual rainfall is much less than 20 inches. These forests, however, are not so much a result of the rainfall in the regions where they occur as of surface and seepage flow from adjacent regions. The mesquite forests of the desert regions of southern Arizona, where the mean annual rainfall is but 8 to 12 inches, are made possible by the seepage and surface waters from the adjacent mountains.

The question of the exact relation which exists between forests and stream flow has long been under discussion. The broad fact that a relation exists is indeed indisputable. Forest destruction always produces a change in the character of the run-off. But the scientific determination of all the causes which produce this effect, and of their relative importance is a difficult and complicated matter. In spite of the fact that for many years European forest experiment stations have been carrying on observations, measurements, and experiments designed to clear up this subject, final conclusions covering the whole field have not yet been established. In this country almost nothing has ever been done to secure accurate data for the investigation of this problem as a whole. Some light, however, has been thrown on the subject by means of a series of observations which have been going on for several years in the San Bernardino Mountains in southern California. It is the purpose of the present article to make clear what are the various factors entering into the problem, and to state some of the more important facts that these observations in southern California reveal.

In the San Bernardino Mountains records of precipitation for several years, at a large number of stations, show that differences in forest cover are closely correlated with differences in rainfall. This correlation is so close that it is possible to judge the mean annual precipitation with a fair degree of accuracy from the appearance of the forest alone. In these mountains forests cover the slopes wherever the mean annual rainfall exceeds 20 to 24 inches; however, on southern and western slopes forests of equal density represent a larger rainfall than on northern and eastern slopes.

Other things being equal, regions having the greatest rainfall bear forests of the greatest density and luxuriancy of growth; but where the mean annual rainfall falls below 18 to 20 inches, types of vegetation in which trees predominate are replaced by those in which shrubs and herbage predominate.

WHAT CAUSES RAINFALL.

Because rainfall is most abundant where forests grow, many believe that forests exert an important influence on the amount of precipitation. A more reasonable inference, however, is that *rainfall is the great factor in controlling the distribution and density of forests.*

Precipitation occurs whenever the air is suddenly cooled below the dew-point. The most effective cause of this is the expansion of air on ascending. This upward movement is caused very largely by cyclonic storms.

Whether forests have any appreciable effect in cooling the air to below the dew-point is uncertain. From the known effect of forests on the temperature and relative humidity of the air, it is reasonable to infer that they may have some such effect, at least to a small degree, and consequently that they have some influence in increasing precipitation. The present evidence, however, derived from many series of observations conducted in Europe and elsewhere, is so conflicting that a definite answer to this question, having the stamp of scientific accuracy, is not possible.

WHAT BECOMES OF THE RAINFALL.

That the excessive destruction of forests is followed by the drying up of streams and springs and by a diminution in the minimum flow of rivers is a well-established fact. The forest is the most effective agent known in regulating the disposition of the precipitation after it reaches the ground.

Rainfall escapes from the ground upon which it falls in five ways—through evaporation, transpiration, surface run-off, seepage run-off, and deep seepage. By evaporation is meant the moisture which passes into the atmosphere in the form of vapor from water and soil surfaces and from objects resting upon such surfaces, including vegetation. Transpiration is that portion of the rainfall which sinks into the soil, and which is later taken up by the vegetation through the roots and given off to the atmosphere through the stems and foliage. To this latter should be added, although not actually a part of it, the comparatively small amount of moisture taken up by the vegetation, but which through chemical change becomes a part of the organic vegetable structure. By surface or superficial run-off is meant that portion of the precipitation which, from the time of falling until its exit from the drainage basin, passes over the surface without gaining access to the soil. On the other hand, by seepage run-off is meant that portion of the rainfall which sinks into the earth, but which later reappears on the surface at lower elevations, and with the surface run-off escapes from the drainage basin in the streams. By deep seepage is meant that portion of the precipitation which sinks into the soil, but to such depths that it does not reappear later on the surface of the drainage basin.

Evaporation and transpiration are frequently classed together as evaporation. In the irrigated parts of the West they are together known as "fly-off." So, also, the rainfall which does not escape through evaporation and transpiration or through deep seepage is often classed as run-off or stream flow.

DO FORESTS INFLUENCE EVAPORATION?

In order that the moisture which falls to the earth in the form of rain and snow should be most efficient in sustaining vegetation and in feeding streams, as little as possible should escape in the form of evaporation. Under the best of conditions a very large part of the annual rainfall is returned to the atmosphere through evaporation. For humid regions, bearing the same types of vegetation, the amount does not vary much from year to year, no matter what the fluctuations in rainfall are—a fact first made known by Messrs. Lawes, Gilbert, and Barrington in the classical Rothamsted investigations. These gentlemen explain this persistency in the rate of evaporation by the fact that heat and abundant rain seldom occur at the same time. Consequently, in a wet season, the lower temperature and more or less saturated atmosphere prevent excessive evaporation; while in a dry season, although the temperature is higher and the air drier, there is less water to evaporate, and the two extreme conditions balance each other so far as the amount of evaporation is considered. This is not true, however, in arid and subarid regions, because during years of minimum rainfall the upper layers of the soil are often so dry for months at a time that there is very little moisture to evaporate, while on the other hand during years of maximum precipitation the atmosphere is not sufficiently saturated to check rapid evaporation.

There is little or no difference between evaporation from a water surface and from any other surface that is thoroughly wet, when both are exposed to the same atmospheric conditions. The evaporation from a water surface is, however, always the same under the same conditions, but it is not the same from other surfaces, because they vary from completely wet to completely dry.

In the forest the crowns of the trees remain wet but a short time after precipitation. During this period, however, the evaporation is undoubtedly very rapid, on account of the large surface and from the fact that the crowns are exposed to the wind and sun. But in a long series of investigations made at the Forest Experiment Station at Nancy, France, and recently published, it was found that a deciduous forest near that station held back from the ground less than 8 per cent of the total precipitation. Although this is almost immediately returned to the atmosphere in the form of evaporation, it is a comparatively small amount of the annual rainfall. On the other hand, evaporation from the soil in the open and in the forest continues often for long periods after the precipitation ceases. After the crowns become dry, evaporation is much retarded in the forest, because the forest floor is protected from the wind and sun. To such an extent is this true that the loss of moisture through evaporation is much less than that lost from an equally saturated soil or from a water surface in the open. Repeated European observations, extending over long periods of time, and shorter observations made in this country, conclusively show that evaporation from water or other wet surfaces on the floor of the forest is but one-third or one-fourth that from similar surfaces in the open. From the investigation of the moisture content of soils in the San Bernardino Mountains, the results of which are as yet unpublished, it appears that the first foot in depth of the mineral soil in the forest may contain two or three times as much moisture as soil of the same general character from similar situations in the open.

During the summer it is impossible to determine by actual measurement the loss of water from the soil either in the forest or in the open, because conditions as to moisture content constantly vary. During the winter, however, the evaporation from a snow surface can be measured with a fair degree of accuracy. Measurements made in the San Bernardino Mountains show that evaporation from snow surfaces may be four or five times as great as from water surfaces under similar exposure, and also that the rate of snow evaporation is profoundly influenced by the wind. In our Western mountains, where the snows are exposed to dry winds, the loss through evaporation is a large percentage of the total snowfall. In the San Bernardino Mountains, snowfalls a foot in depth are sometimes evaporated in two or three days without even moistening the soil. In so far as forests check the winter winds and provide shade, they lessen winter evaporation. This lessening of the evaporation from snow surfaces, through the action of forests, is seen in the fact that snows linger much later in spring in well-wooded regions than in open areas.

It appears, then, that forests materially retard evaporation, both of soil moisture and of snowfall.

DO FORESTS INFLUENCE TRANSPIRATION?

When land is covered with vegetation a certain amount of the rainfall is taken up by the growing plants. A small part, through chemical change, becomes incorporated into the plant, but the larger part is returned to the atmosphere through transpiration. Although those who have investigated this subject are by no means in accord, there is reason to believe that considerable difference exists in the amount of water taken up by the different types of vegetation in the process of growth. On the whole, the forest probably takes up less water from the soil than the average agricultural crop. Risler, from a lengthy series of investigations, reached the conclusion that forests actually take up less than one-half as much water from the soil as the average agricultural crop.

The above would lead one to infer that where the soil, if not covered with forest growth, is clothed with grass or some other low form of vegetation, the return of moisture to the atmosphere, through evaporation and transpiration, or, in other words, the "fly-off," is less from the forest than from the open. But in regions having a short wet season followed by a long dry one the return of moisture to the atmosphere is probably greater from a forested area, because in the open for a large part of the year there is very little to evaporate, and the scanty growth of grass and other low forms of vegetation gives little opportunity for loss through transpiration.

THE INFLUENCE OF FORESTS IN REGULATING THE RUN-OFF.

Stream flow consists of both surface run-off and seepage run-off. Although these two can not be separately determined, total run-off admits of accurate measurement. Surface run-off may be considered as flood water, while seepage run-off is that portion of the drainage which gives the streams a sustained flow. It is evident that any factor which decreases the surface or superficial run-off and increases the seepage run-off is of the utmost importance in regulating the flow of streams.

The proportion of flood water to seepage is influenced by the rapidity of the rainfall. It is well known from direct observation that a slowly falling, prolonged rain, even on the naked soil of steep slopes, is all taken up by the soil. On the other hand, a heavy shower of short duration, falling on the same slope, may largely escape as run-off. In the first instance each drop has time to be absorbed by the soil, while in the latter the accumulation of drops is more rapid than the absorption, and the excess moves over the surface to lower elevations. The forest canopy very perceptibly extends the period of time during which the rain reaches the soil, and in this way lessens surface run-off.

Again, forests, by checking the velocity of the wind and covering the mineral soil with a thick layer of dead leaves and other forest litter, effectively prevent soil transportation by both wind and water. On high elevations, where streams generally have their birth, the influence of the forest in this respect is of the utmost importance. So great is this influence that it exerts a marked effect upon topography. In mountainous regions particularly, the repeated destruction of forests permits the soil formed by the decomposition of the rocks at the sources of streams to be transported to lower elevations, with a consequent slow change in the details of the landscape. Such regions, if unforested, are apt to have precipitous slopes and scanty soil on the higher elevations. In that case there is no adequate medium to absorb the rain, and it flows over the surface. On the other hand, if such regions are well wooded, the slopes are less precipitous, and a considerable depth of soil usually covers the broad summits. As a result, the rain water is absorbed and the surface flow is reduced to a minimum.

Not only is it essential to have an adequate medium present to absorb the rain, but it must be of such character as to absorb quickly. The rapidity with which rain is absorbed is very largely governed by the physical properties of the soil, the organic litter upon it, and the vegetation. Decayed organic matter, by itself or in combination with mineral soil, absorbs moisture much more rapidly than soil containing little or no organic matter; hence, the greater the amount of leaf mold and other litter, the more rapidly will the rain be absorbed. Rapidity of absorption is also influenced by the degree of looseness of the mineral soil. In the forest the mulch of leaves and litter keeps the mineral soil loose and in the best condition for rapid absorption.

Not all the rain that is not absorbed by the soil where it falls reaches the streams by flowing over the surface. Much of it is taken up in passing from the place of falling to the stream. The amount taken up depends upon the obstructions in its pathway. Where there are no obstacles, as on barren ground, the moving water, by eroding channels, forms small rivulets, and these larger and larger ones, which flow with constantly increasing velocity. As a result, the water passes rapidly over the surface, and but little gets into the soil. When the soil is covered with obstructions, such as are offered by a forest with its accumulation of litter and vegetable growth, the rain which is not immediately absorbed is checked in its flow over the surface. The water, being held back, is finally taken up by the soil and thus prevented from forming small rivulets through erosive action.

The forest, in extending the time during which the rain reaches the soil, in its effect upon local topography, and in supplying a larger and better absorbing medium, must necessarily have a profound influence in increasing the seepage run-off, and in proportionately decreasing the surface flow.

COMPARISON OF RUN-OFF FROM FORESTED AND NONFORESTED AREAS.

There are so many complex conditions influencing the flow of streams that it is extremely difficult to determine the effect of forests on run-off by the comparison of the discharge of streams on forested and nonforested catchment areas. It is believed by many that stream flow is so largely influenced by the amount, intensity, and character of the precipitation, the configuration and area of the catchment basin, the character of the absorbing medium and the underlying rocks, and the general climate, as well as the forest itself, that we shall probably never be able to measure quantitatively the influence of forests on the flow of streams by the comparison of forested and nonforested regions. Catchment areas differ so greatly in the features mentioned above that our most conservative and able investigators have been forced to the conclusion that "in respect to run-off, each stream is a law unto itself." Although the above is probably in the main true, yet, by the careful selection of small catchment basins for comparison, it appears that the influence of the forest in diminishing the surface run-off can be determined with a fair degree of accuracy. When the catchment areas compared are in the same region, are influenced by the same or nearly the same climate and precipitation and by the same storms, have approximately the same configuration and area, and have a similar mineral soil and underlying rocks, the effect of these various factors on the run-off can be ignored, and the differences in the behavior of the stream flow on the forested and nonforested areas can be assigned to the influence of the forest.

In a careful study of the behavior of the stream flow on several small catchment areas in the San Bernardino Mountains, it has been found that the effect of the forest in decreasing surface flow on small catchment basins is enormous, as shown in the following tables, where three well-timbered areas are compared with a nontimbered one:

Precipitation and run-off during December, 1899.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	19+	36−	3
1.05	.....do	19+	73+	6
1.47	.....do	19+	70−	6
.53	Nonforested	13−	312+	40

At the beginning of the rainy season, in early December, the soil on all four of these basins was very dry as a result of the long dry season. The accumulation of litter, duff, humus, and soil on the forest-covered catchment areas absorbed 95 per cent of the unusually large precipitation. On the nonforested area only 60 per cent of the precipitation was absorbed, although the rainfall was much less.

Rainfall and run-off during January, February, and March, 1900.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	24	452+	35
1.05	.....do	24	428+	33
1.47	.....do	24	557+	43
.53	Nonforested	16	828+	95

The most striking feature of this table as compared with the previous one is the uniformly large run-off as compared with the rainfall. This clearly shows the enormous amount of water taken up by a dry soil, either forested or nonforested, as compared with one already nearly filled to saturation. During the three months here noted, on the forested basins about three-eighths of the rainfall appeared in the run-off, while on the nonforested area nineteen-twentieths appeared in the run-off.

Rapidity of decrease in run-off after the close of the rainy season.

Area of catchment basin.	Condition as to cover.	Precipitation.	April run-off per square mile.	May run-off per square mile.	June run-off per square mile.
Sq. miles.		*Inches.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
0.70	Forested	1.6	153−	66−	25−
1.05	.....do	1.6	146−	70+	30−
1.47	.....do	1.6	166+	74+	30+
.53	Nonforested	1	56+	2−	0

The above table clearly shows the importance of forests in sustaining the flow of mountain streams. The three forested catchment areas, which, during December, experienced a run-off of but 5 per cent of the heavy precipitation for that month, and which during January, February, and March of the following year had a run-off of approximately 37 per cent of the total precipitation, experienced a well-sustained stream flow three months after the close of the rainy season. The nonforested catchment area, which, during December, experienced a run-off of 40 per cent of the rainfall, and which during the three following months had a run-off of 95 per cent of the precipitation, experienced a run-off in April (per square mile) of less than one-third of that from the forested catchment areas, and in June the flow from the nonforested area had ceased altogether.

DO FORESTS INCREASE THE RUN-OFF?

Owing to the very complex nature of the investigation involved in determining the effect of forests on the amount of run-off, the available evidence does not admit a definite answer that will be of general application. It is reasonably certain from present evidence that in some regions the effect of the forest is materially to increase the run-off. It appears equally certain, however, that in other regions, and on certain classes of catchment areas, the effect of the forest is to materially decrease the stream flow.

Mr. Rafter, in his recent publication, "Relation of rainfall to run-off," makes this statement: "With similar rainfalls, two streams, one in a region having dense primeval forests, the other in a region wholly or partially deforested, will show different run-off. The one with the dense forest will show a larger run-off than the stream in the deforested area." This author concludes, from the careful study of a large number of catchment areas in the State of New York, that the effect of the forest on at least a portion of the area studied is to increase the run-off to an amount equal to from 5 to 6 inches in depth over the entire catchment area.

In humid regions, where the precipitation is fairly evenly distributed over the year, and where the catchment area is sufficiently large to permit the greater part of the seepage to enter the stream above the point where it is gauged, the evidence accumulated to date indicates that stream flow is materially increased by the presence of forests.

In regions characterized by a short wet season and a long dry one, as in southern California and many other portions of the West, present evidence indicates, at least on small mountainous catchment areas, that the forest very materially decreases the total amount of run-off.

Annual rainfall and run-off on forested and nonforested catchment areas in the San Bernardino Mountains, California.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	46	731	28
1.05	.....do	46	756	30
1.47	.....do	46	904	36
.53	Nonforested	33	1,192	69

On small nonforested catchment areas in the West, and possibly on large ones as well, a very large part of the heavy precipitation of the rainy season flows over the surface, quickly reaches the stream, and is discharged from the catchment area as flood water, much as water escapes from the roof of a building. On such areas the actual loss through evaporation during the dry season is probably far less than from a well-wooded area, because the surface soil and streams are dry and there is very little moisture left to evaporate. On such denuded areas it appears that the run-off for the few months that the streams flow is considerably larger than that for the entire year from similar forested areas. Although a nonforested area may, in certain instances, produce a larger run-off than a forested one, this probably never occurs except when the run-off from the nonforested area is largely flood water, and of destructive rather than constructive significance.

CONCLUSION.

In conclusion, it may be said that although the forest may have, on the whole, but little appreciable effect in increasing the rainfall and the annual run-off, its economic importance in regulating the flow of streams is beyond computation. The great indirect value of the forest is the effect which it has in preventing wind and water erosion, thus allowing the soil on hills and mountains to remain where it is formed, and in other ways providing an adequate absorbing medium at the sources of the water courses of the country. It is the amount of water that passes into the soil, not the amount of rainfall, that makes a region garden or desert.

Walter Mulford

INFLUENCE OF FORESTRY UPON THE LUMBER INDUSTRY.

BY

OVERTON W. PRICE,
Assistant Forester, Bureau of Forestry.

[REPRINT FROM YEARBOOK OF DEPARTMENT OF AGRICULTURE FOR 1902.]

CONTENTS.

Page

Development of the lumber industry 309

Some results to be secured by conservative lumbering 310

Elimination of the large sawmill 311

Development of a trained class of forest workers 311

Influence of forestry upon the prices of lumber 312

Conclusion 312

ILLUSTRATIONS.

Page.

PLATE XXX. Fig. 1.—Whip sawing in the Kentucky Mountains. Fig. 2.—A modern sawmill in the Sierras, California 310

XXXI. Cut-over Red Fir land 310

XXXII. Fig. 1.—The result of lumbering and fire in Minnesota. Fig. 2.—Logging Red Fir in Washington 310

THE INFLUENCE OF FORESTRY UPON THE LUMBER INDUSTRY.

By Overton W. Price,
Assistant Forester, Bureau of Forestry.

DEVELOPMENT OF THE LUMBER INDUSTRY.

The development of the lumber industry in this country is without parallel. It now ranks fourth among the great manufacturing industries of the United States, and represents an invested capital of about $611,000,000 and an annual outlay of over $100,000,000 in wages. It affords through its three great branches—the logging industry, the sawmill industry, and the planing-mill industry—a means of livelihood to considerably over a million persons. The annual value of the products, which has multiplied nearly ten times in the last half century, is $566,000,000. But although the rapid development of the lumber industry has had far-reaching results in furthering every branch of manufacture which depends upon wood, it has been fundamentally unsound in principle. The settler who cuts and sells trees without forethought from land fit only for forest growth has not enriched himself in the long run. The havoc which has been wrought in the forests of the United States has turned trees into money, but has put the balance on the wrong side of the sheet by rendering vast areas unproductive. It is the history of all great industries directed by private interests that the necessity for modification is not seen until the harm has been done and its results are felt. This fact has been emphasized in the lumber industry—in the earlier days by the instinctive feeling of the colonist against his natural enemy, the forest, and later by the remarkable inducements offered by lumbering for present profit only. The first settlers had two objects in view in their attack upon the forest—the one to clear land for their farms, the other to procure wood for their buildings, fuel, and fences. As the tide of colonization rose, and as the uses for wood in manufacture increased in number and extent, lumbering rapidly assumed the proportions of a business enterprise, and from supplying only personal wants it became profitable to supply also those of others. With an apparently inexhaustible supply of timber available, and with an insistent and growing demand, the lumber industry came to offer remarkable opportunities for money making. Step by step with its development improvement in tools and machinery took place. The changes that enterprise and ingenuity have wrought in the American sawmill are no less wonderful than those which have taken place in the

American locomotive. From "whip sawing," in which the boards were sawed out by hand, to the modern steam sawmill, with its railroad (Pl. XXX), its planing mill, and its cut of nearly half a million board feet per day, is a long step—but it has not taken much over fifty years to accomplish it. In effective methods for the harvesting and manufacture of lumber the American lumberman has no superior, nor is he equaled in his disregard for the future of the forest which he cuts.

SOME RESULTS TO BE SECURED BY CONSERVATIVE LUMBERING.

It is natural that the lumberman should not turn eagerly from a system whose only aim is to secure the highest possible present profit from the forest to one which includes provisions for the production of a second crop upon the lumbered area. Under conservative methods lumbering becomes a legitimate industry for the production as well as for the consumption of its staple. It no longer offers, however, the short cut to fortune which it proved to be so long as an abundance of timber rendered the old methods of lumbering possible. It is difficult for lumbermen generally to realize that the time for practical forestry has fully arrived. But signs more significant than any existing statistics point to the imminent failure in the supply of certain timbers in the United States. From the data available, there is no way to foretell accurately the time necessary to exhaust this supply of merchantable timber at the present rate of consumption. A good many estimates of the merchantable timber standing have been made, some of which have already proved fallacious. To predict accurately how long it will be before the United States is confronted by a timber famine would require first of all a knowledge of the composition, quality, and condition of the forests, which it would take many years to obtain. At present such an estimate is of little practical value. We do know that the supply of timber of many kinds is failing, of other kinds is almost exhausted, and of others is practically gone; that Black Walnut is no more to be had except in small quantities and at enormous expense; that first-growth White Pine is growing rapidly to be a rarity on the market; that where the supply of spruce for pulpwood and for lumber for the next ten years is to be found is a grave question before the lumbermen to-day. The list of woods accepted as merchantable lengthens from year to year, species hitherto considered valueless being harvested more and more willingly as the result of the exhaustion of more valuable kinds. In spite of steady improvement in tools, logging outfits, and mill machinery, all tending to cheapen the cost of lumbering, the price of lumber increases steadily and rapidly. These are facts more significant than predictions in terms of years of the life of the lumber industry. The exact period for which the existing supplies are sufficient is a matter of

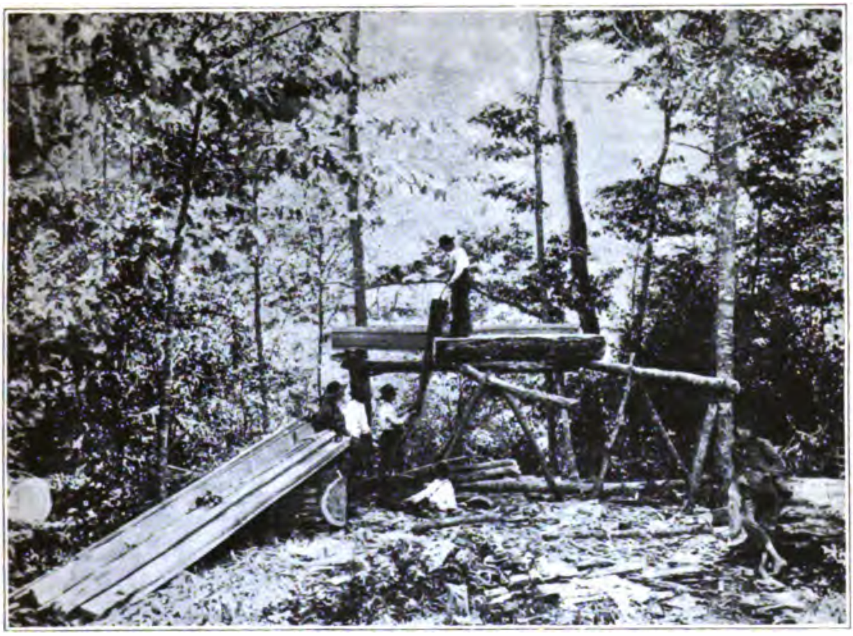


FIG. 1.—WHIP SAWING IN THE KENTUCKY MOUNTAINS.

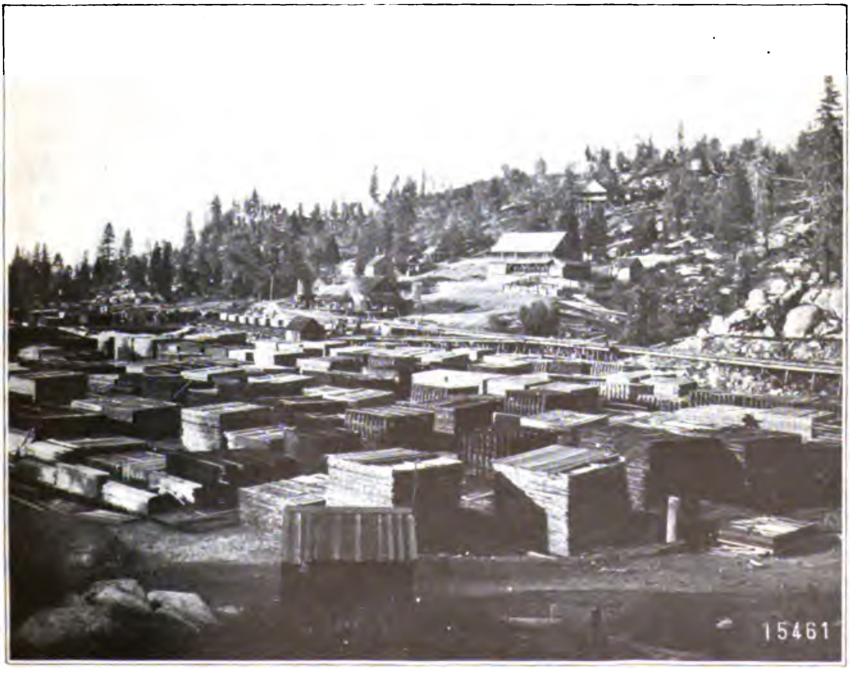
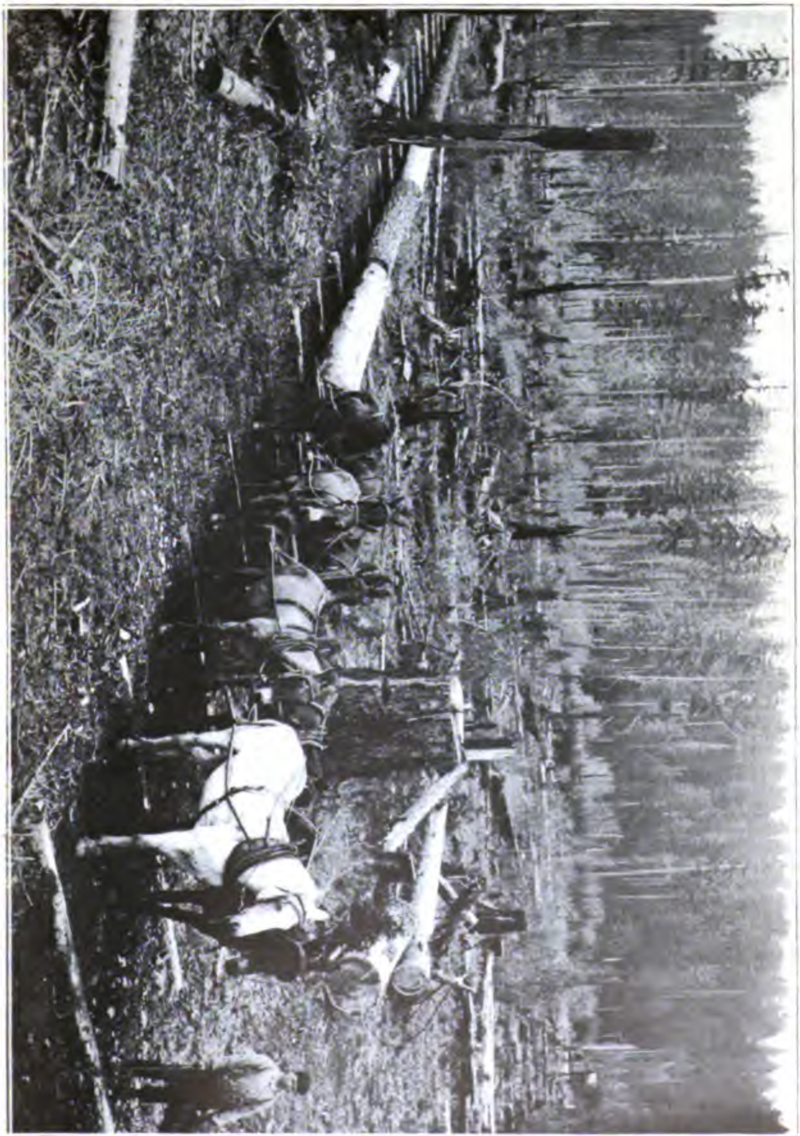


FIG. 2.—A MODERN SAWMILL IN THE SIERRAS, CALIFORNIA.



CUT-OVER RED FIR LAND.

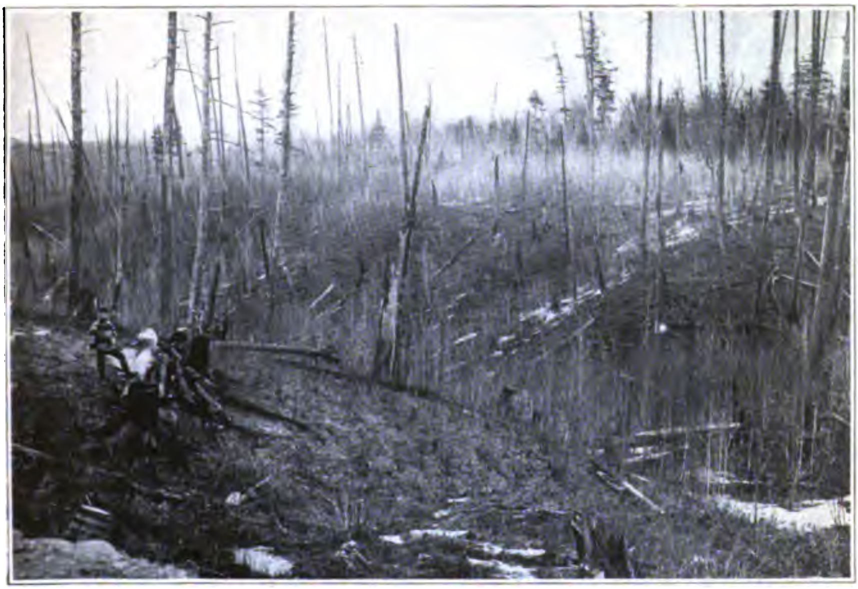


FIG. 1.—THE RESULT OF LUMBERING AND FIRE IN MINNESOTA.

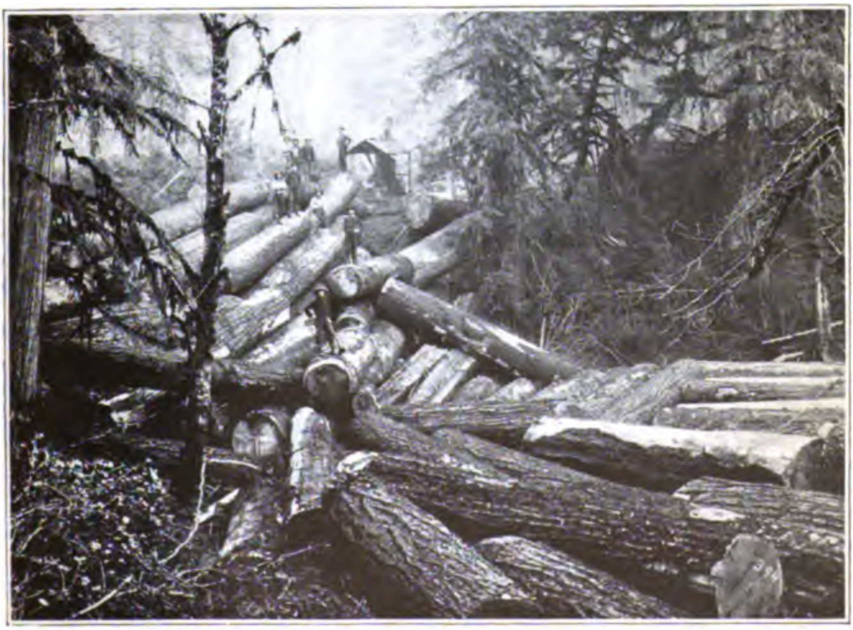


FIG 2.—LOGGING RED FIR IN WASHINGTON.

detail. The vital point lies in the crisis which the lumber industry is approaching in the exhaustion of the material on which its existence depends. (See Pls. XXXI and XXXII.)

ELIMINATION OF THE LARGE SAWMILL.

The general application of forestry to forest lands owned by lumbermen will probably result in the gradual elimination of the large sawmill and the substitution of those of moderate size. The mammoth milling plant will be rare when only second growth is left to supply it, for the area of timber land sufficient to produce the logs necessary to run such a plant is enormous. It is reasonable to expect that the mill of moderate size, supplied by a forest whose production is equal to the mill's annual capacity, both under the same management, will become more and more the rule. The very existence of the enormous mill is the result of an abundance of timber resources, which exist no longer except in a very few sections. In Europe the long-continued application of conservative measures in lumbering has resulted in a distribution and type of sawmill little known in this country. Sawmills of large size do not exist, but in their stead small sawmills, for which water generally supplies the power, are distributed throughout the country wherever the local demand is sufficient to keep them running. Their annual cut is for the most part exceedingly small, according to our standards, and sufficient only to supply the wants of the immediately adjacent country. The mills saw largely on order, and the fact that their construction is permanent and their motive power cheap enables them to run intermittently without loss. The results are upon the whole exceedingly satisfactory. The man who wants lumber gets it promptly, and without paying an added cost for long transportation. The antiquated construction of European sawmills is often such that the American lumberman would find in them but a proof of his superior ingenuity; but the European distribution of milling plants has its strong advantages in several ways.

DEVELOPMENT OF A TRAINED CLASS OF FOREST WORKERS.

The general application of conservative methods in lumbering will inevitably result, as has been the case in Europe, in the development of a permanent class of men trained to forest work. Under present methods this result can never be attained to the same degree. The lumbering in one community is generally so short-lived that there is neither time nor necessity to train up a body of men on the ground to carry out the work. The result is that Maine and Michigan woodsmen are found working in the hardwoods of the Southern Appalachians; loggers from Wisconsin and Minnesota are helping to cut the redwood on the Pacific coast; and in each of the great timber regions there is a mingling of lumbermen from several of the others. The effect has been to develop, by constant labor at their trade under widely varying conditions, a force of men who are unequaled for enterprise and skill in their profession; but the system has very largely failed in what is of infinitely greater importance to the permanent welfare of the lumber industry—the upbuilding throughout the country of a stable class of workers in the woods, locally trained and carrying on their work each in his own community. The advantages of such a condition lie in an equitable geographical distribution of labor, in the wholesome influence throughout the country of a class whose means of livelihood is forest work, and in the fact that all the operations of lumbering may in this way be conducted more cheaply than in any other.

INFLUENCE OF FORESTRY UPON THE PRICES OF LUMBER.

The effect upon the prices of lumber which will result from the application of forestry to the lumber industry will be strongly marked. The wide fluctuation characteristic of lumber values to-day is much more the result of conditions within the industry itself than of variations in the demand for the product of the forest. The uncertainty of available supplies, the lack of true proportion between stumpage values and lumber values, the speculative features which the industry now presents, have all tended to produce an exceedingly unstable and abnormal fluctuation in the prices of lumber, with a marked disposition toward rapid increase. Under forestry the speculative element can not exist. The cost of producing timber, plus a legitimate profit, will be the basis upon which the value of it will be fixed. The annual output of the country will be no longer a matter of conjecture, and a steady and normal range of prices for lumber will be the inevitable result.

CONCLUSION.

The influence of forestry upon the lumber industry is not a matter of conjecture. The details will have to work themselves out, but the broad results of conservative forest policy on the part of private owners are plain. The lumber industry in the United States is approaching a crisis. There is no more doubt that conservative methods will be applied to lumbering in this country than there is of the development of irrigation, of regulation of grazing, of the application of improved methods in agriculture, or of any other modification to which private as well as public interests point the way. How long it will be before the results of practical forestry make themselves generally felt it is impossible to foretell; but the fact remains that there will be established in this as in other countries in which conservative lumbering has followed wasteful lumbering a legitimate and permanent industry, characterized, as has been stated, by conditions under which speculation can not exist. Prices will continue normal and steady, and the quantity of timber produced will be the main factor in regulating consumption.

Walter Mulford

Mis. Circular No. 3.

United States Department of Agriculture,

THE MISSISSIPPI RIVER FLOOD.

[Report No. 2.]

Since the publication, on April 12, of a statement relative to the agricultural interests of the submerged districts of the Mississippi Valley south of Cairo, Ill., the area under water has been considerably extended.

EXTENSION OF FLOODED REGION.

This extension is below Vicksburg, Miss., but on the right, or west, side of the river, and is mainly due to a break, 2,000 feet in width, in the levee at Biggs. The outflow of water at this point has totally submerged four parishes (counties) of Louisiana, and partially overflowed five others, while a break at Lafourche Crossing, in the southern part of the same State, has resulted in the submergence of an additional area of nearly 300 square miles in Lafourche and Terrebonne parishes.

In this newly submerged region there was in 1890 a total population of 82,356, in the proportion of four colored persons to one white.

FARMS, ACREAGE, AND PRODUCTS.

The region contained at the last census 7,747 farms, with a total area of over 1,000,000 acres, of which 420,000 acres were improved. Of this last mentioned area 213,000 acres, or over one-half, were last year devoted to cotton, over 91,000 acres to corn, 6,000 acres to sugar cane, 2,000 acres to hay, and an inconsiderable acreage to other crops.

The total value of these farms, including fences and buildings, but exclusive of their movable equipment, was in 1890 close upon $11,000,000, and the value of the implements and machinery upon them was over $600,000. On January 1 of the present year they contained live stock to the value of one and one-half million dollars, and so lately as the 1st of March last they were estimated to have still on hand about $800,000 worth of the crops of last season. The total value of the farms submerged by the breaks in the levees that have occurred since the 10th instant, with their farm implements, live stock, and crops on hand, is, therefore, close upon $14,000,000.

This region produced last year nearly 100,000 bales of cotton, over 9,000,000 pounds of sugar, over 1,300,000 bushels of corn, besides hay, potatoes, oats, and other minor products, the entire production aggregating a value, even at the low prices that prevailed, of more than four and one quarter million dollars.

TOTAL SUBMERGED AREA AND ITS AGRICULTURAL INTERESTS.

The total area submerged at this date is over 20,000 square miles. It contained at the last census 46,935 farms, with a total area of 4,904,466 acres, nearly one-half of which was improved, and a total population, agricultural and other, of 462,041. If, to the value of its farms, farm buildings, and farm machinery, according to the census of 1890, there be added the value of its live stock on January 1

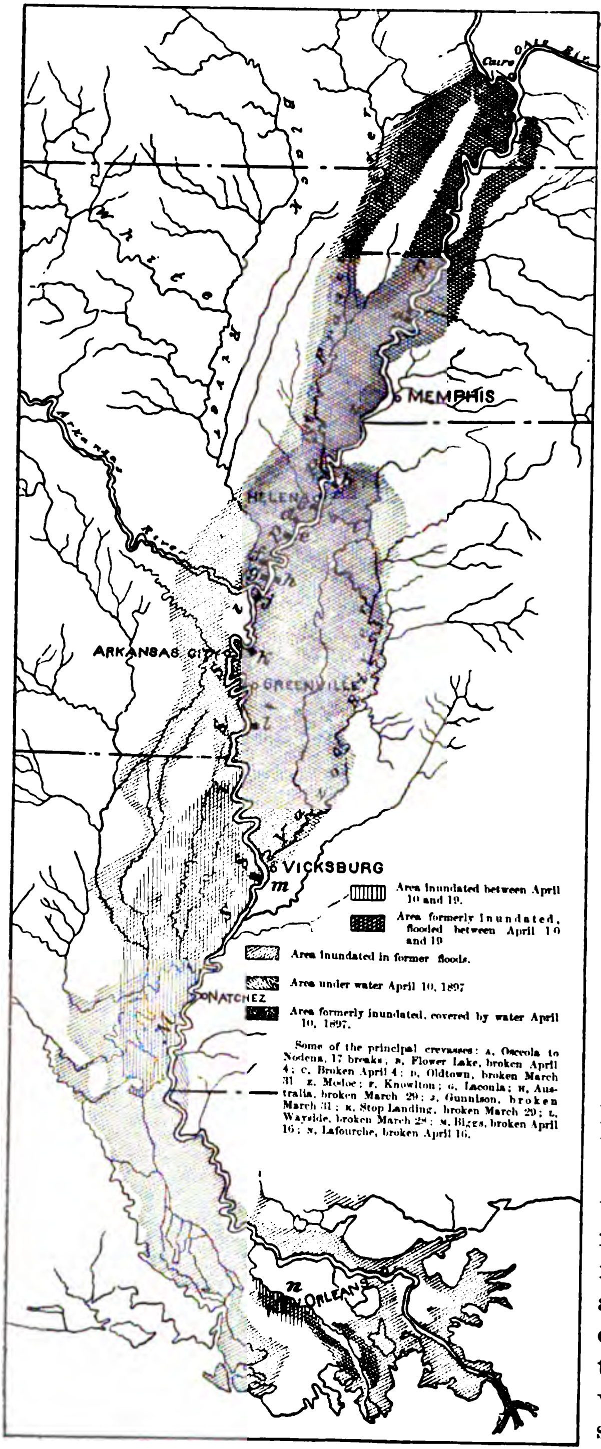

Cairo
Ohio R.
St. Francis River
MEMPHIS
Arkansas River
HELENA
ARKANSAS CITY
GREENVILLE
VICKSBURG
NATCHEZ
N. ORLEANS
Area inundated between April 10 and 19.
Area formerly inundated, flooded between April 10 and 19
Area inundated in former floods.
Area under water April 10, 1897
Area formerly inundated, covered by water April 10, 1897.
Some of the principal crevasses: A, Osceola to Nodena, 17 breaks; B, Flower Lake, broken April 4; C, Broken April 4; D, Oldtown, broken March 31 E, Meloe; F, Knowlton; G, Laconia; H, Australia, broken March 29; J, Gunnison, broken March 31; K, Stop Landing, broken March 29; L, Wayside, broken March 28; M, Biggs, broken April 16; N, Lafourche, broken April 16.

FIG. 1.—Map of the Mississippi River flooded district (prepared under the direction of the Chief of the Weather Bureau).

last ($9,174,636), and of its products of last season still on hand on March 1 last ($4,595,179), the total of $90,176,177 will represent the approximate value of the agricultural property of the submerged region. Among the products of this region last year were 466,056 bales of cotton, worth $16,312,060; 12,525,645 bushels of corn, worth $3,995,278, and 9,033,878 pounds of sugar, worth $271,016, the total production, including minor crops, representing a value of $21,782,180 on the plantation.

FARM PROPERTY LIABLE TO DAMAGE.

The accompanying tables, prepared under the direction of the Statistician, contain an estimate of the amount of farm property liable to damage in the flooded district of Louisiana.

Table No. 1 shows the estimated population of the flooded district, by color.

Table No. 2 contains the estimated number of farms, the total number of acres, the acres improved, and the acreage under the principal crops in 1896.

Table No. 3 shows the estimated capital invested.

Table No. 4 shows the quantities and values of the principal farm products raised in the flooded territory in 1896.

As the Division of Statistics makes no estimates of crops by counties, the proportions existing between the counties in the flooded districts and the total for the State during the census year have been presumed to be correct for the present period, and have been used in making these estimates.

LOUISIANA.

TABLE NO. 1.—*Population of flooded territory, 1890.*

White	17,275
Colored	65,081
Total population	82,356

TABLE NO. 2.—*Number and acreage of farms submerged April 19, 1897.*

Number of farms	7,747
Number of acres in farms	1,027,265
Number of acres improved	420,488
Acreage under principal crops in 1896:	
Cotton	213,465
Corn	91,507
Sugar	6,000
Hay	2,014
Potatoes	800
Oats	494
Total acreage under principal crops	314,280

Table No. 3.—*Capital invested.*

Value of farms and improvements	$10,956,945
Value of implements, etc	611,809
Cost of fertilizers	22,097
Value of live stock on hand January 1, 1897:	
Horses	262,841
Mules	712,994
Milch cows	181,368
Other cattle	158,529
Sheep	4,868
Swine	169,845
Total value of live stock	1,490,445
Value of crops on hand March 1, 1897:	
Corn	191,067
Wheat	....
Oats	1,680
Cotton	605,190
Total value of crops on hand	797,937
Total capital invested	13,879,233

Table No. 4.—*Quantities and values of the principal farm products raised in the flooded territory of Louisiana in 1896.*

	Production.	Value.
Crops of 1896:		
Cotton ... bales	96,059	$3,362,165
Corn ... bushels	1,326,852	597,083
Sugar ... pounds	9,033,878	271,016
Hay ... tons	3,827	33,846
Potatoes ... bushels	44,000	33,440
Oats ... do	4,940	1,680
Total value of crops		4,299,230
Live stock raised in 1896:*	*Number.*	
Horses foaled	771	7,247
Mules foaled	62	930
Calves dropped	6,541	22,772
Lambs dropped	1,237	1,113
Total value of live stock		32,062
Total value of crops and live stock		4,331,292

---

* As all live stock shown in Table 4 must be less than one year old, the average value is necessarily low.

Chas. W. Dabney, Jr.,
Special Agent in Charge of
Scientific and Statistical Work.

Approved:
James Wilson,
Secretary.
Washington, D. C., *April 22, 1897.*

1457 Issued July 20, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—CIRCULAR 117.

A. C. TRUE, Director.

Walter Mulford

A WORKING EROSION MODEL FOR SCHOOLS.

BY

DON CARLOS ELLIS,

In Charge, Educational Cooperation, Forest Service.

ISSUED BY THE
OFFICE OF EXPERIMENT STATIONS
IN COOPERATION WITH THE
FOREST SERVICE.

[H. S. GRAVES, Forester.]

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., April 26, 1912.

SIR: I have the honor to transmit herewith and to recommend for publication as a circular of this office a manuscript describing a working erosion model designed to illustrate graphically the erosion of hillsides and the destruction of farms in the lower valleys following the complete removal of forests from the hills. The model has been thoroughly tested at expositions and is one that can easily be constructed in a school building for use by classes in nature study, agriculture, and physical geography.

Respectfully,
A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

ILLUSTRATIONS.

Page.

Fig. 1. Model showing the effects of rainfall upon two adjacent hills, one covered with forest growth and the other devoid of such protection..... 5
2. Top plan of model.. 7
3. Vertical section of model.. 8
4. Front elevation of model.. 9

A WORKING EROSION MODEL FOR SCHOOLS.

ESSENTIAL FEATURES OF THE MODEL.

A working model showing the processes of erosion on deforested slopes has been a feature of exhibits made by the Forest Service at recent expositions. It shows the working out of the natural phenomena so well, and is so simple and inexpensive to construct, that a description is here given of a similar model which might be erected in schools for the use of classes in nature study, elementary agriculture, and physical geography.

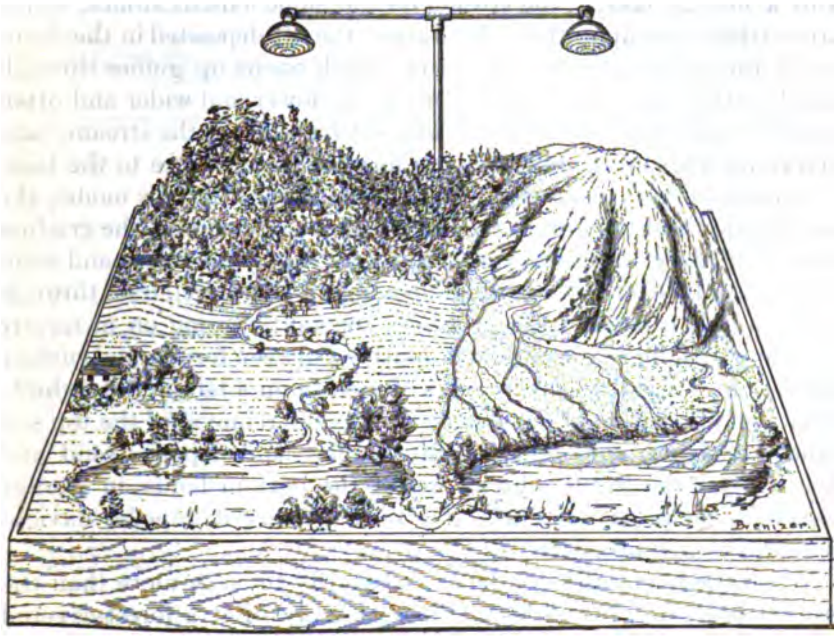


Fig. 1.—Model showing the effects of rainfall upon two adjacent hills, one covered with forest growth and the other devoid of such protection.

The model consists of two hills sloping down into two valleys through which two streams wind in and out through farm land and lead into two lakes at the front of the landscape. (Fig. 1.) Both hills are made of the same kind of soil, that of the region in which the model is erected, but one is covered thickly with twigs, young trees, or shrubs, to simulate a forest, underneath which is a heavy carpet of moss representing the layer of leaves and twigs which covers the ground in the real forest, while the other hill is bare of all vegetation.

By means of a suitable sprinkling device water in the form of rain is made to fall with equal force upon the two hills. On the forested slope its fall is broken by the foliage and it drops gently upon the moss-covered surface of the ground. The moss and the soil beneath, which is kept soft and porous by the protective cover, quickly absorb the rain and allow it to seep out as clear water farther down the slope, thus forming a mountain stream which flows through a green and fertile valley into a clear lake at the lower end of the model.

On the other slope the rain beating down upon the unprotected and hardened surface washes deep gullies in the hillside, carries the soil into the turbid stream which drains the valley below, and thence into a muddy lake. The erosion on the slope loosens stones, which are carried down upon the valley farms; the silt deposited in the channel of the stream diverts the water, which opens up gullies through the dry land; the main stream is made shallower and wider and often overflows into the fields; islands and silt bars rise in the stream; and deltas are built up in characteristic form at the entrance to the lake.

The erosion processes which work themselves out in this model, the wearing down of the hill, the silting up of the stream bed, the gradual shifting of the course of the stream, the formation of deltas and sand bars in the lake, and the gradual opening up of watercourses through them are all typical of the processes constantly going on in nature and show strikingly the close relationship between forests and surface formation. It is the same process of erosion on a larger scale which, after the destruction of our forests, causes the removal of the top soil from our slopes, cuts them up into gullies, and deposits sand and gravel upon the fertile alluvial soil of the bottom lands, in storage reservoirs, or in the channels of streams, where it impedes navigation and causes overflow.

While the model is not intended primarily to show more than the erosion processes, it can be used to show also that a forest-covered slope acts as a reservoir in impounding the water and allowing it to seep slowly into the streams, and, on the other hand, that water runs off the surface of a bare slope as soon as it falls, resulting in floods when the precipitation is heavy and in droughts during a dry season. If the sprinkler is stopped and all the water taken out of both of the streams and the lakes, the lake on the forested side will, within a few hours, receive a considerable amount of water as seepage from the wooded hillside, while the other lake will remain practically empty.

CONSTRUCTION OF THE MODEL.

Convenience may determine the size of the model. It may be as small as 4 feet square, but 7 feet square is probably a better size for working out all of the phenomena. Directions are here given for a model 5 feet square.

Construct a strong tray measuring, on the inside, 5 feet square and about 6 inches deep, with the sides reenforced with heavy nails so as to resist the warping of the wood when wet. The bottom of the tray should be made of tongued and grooved material running from front to rear and made water-tight with lead paint between the planks and paraffin over the seams. (Fig. 2.) The paraffin should be applied hot and plenty should be used. The rear of the tray might be placed against the wall 2 feet 4 inches from the floor, and the front placed on legs 2 feet high. This will give a sufficient slant for good drainage. (Fig. 3.)

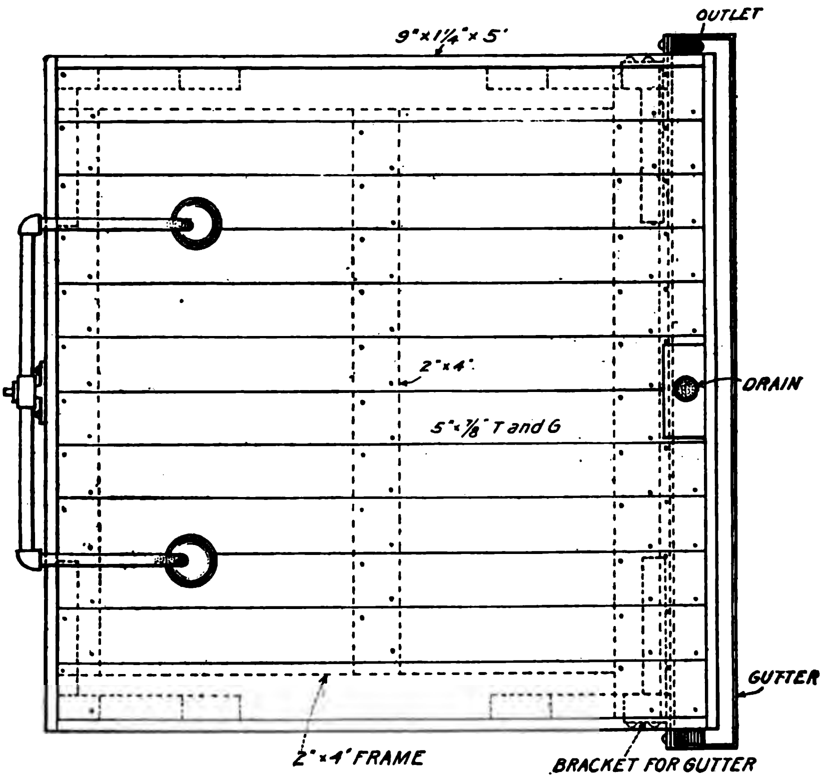


Fig. 2.—Top plan of model.

Now fill the tray within about 2 inches of the top with rubble and earth, with the general slant of the surface toward the center of the front of the tray. Slight depressions should be made in the soil, as foundations for the two streams, and two large depressions should be left in the front corners for the lakes. Drainage of these lakes should be provided for by shallow channels running from their surfaces to a drainpipe in the middle of the front of the tray or in some other suitable place.

Next, place from 1 to 2 inches of mortar, consisting of about one part cement and two parts sand, over the entire surface. The mortar should be stiff enough to maintain its shape. Work in the stream beds and the lake depressions before the mortar sets, taking care that the outlets of the lakes are only slightly lower than the intakes at the mouths of the streams. Of course, the more irregular the stream beds are made, the more natural will they appear when finished. Little sinuses, swimming holes, obstacles, and inequalities in elevation to create waterfalls, and similar natural touches will add attractiveness. In applying the mortar care should be taken to retain the general direction of the slant toward the center of the front

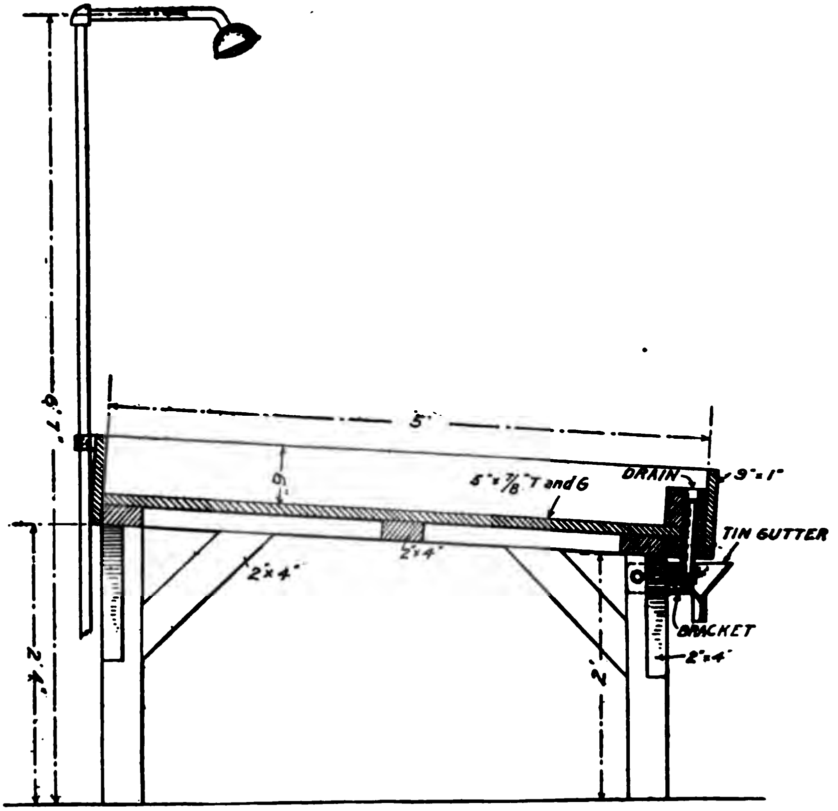


FIG. 3.—Vertical section of model.

of the model. Let the mortar dry out for several days, then paint the surface with hot paraffin and burn in the paraffin with a plumber's hand furnace or Bunsen burner. The model should now be waterproof, but it is safer to run a gutter along the front to receive the drippings. (Fig. 4.) The drain from the surfaces of the lakes should also be directed into this gutter, which should empty into a waste pipe.

When the mortar is hard, erect a mound of earth on each of the rear corners of the model, about 1½ feet in height, and so arranged that the front slope of each drains into one of the streams. The hills may be made to appear as two peaks, with a depression between them. Cover one of the mounds thoroughly and thickly with moss, which can be gathered in the woods or purchased by the sack from a florist, and through this moss stick small twigs or trimmings of hedges to represent a forest. Cedar, arbor vitæ, or juniper twigs prove most

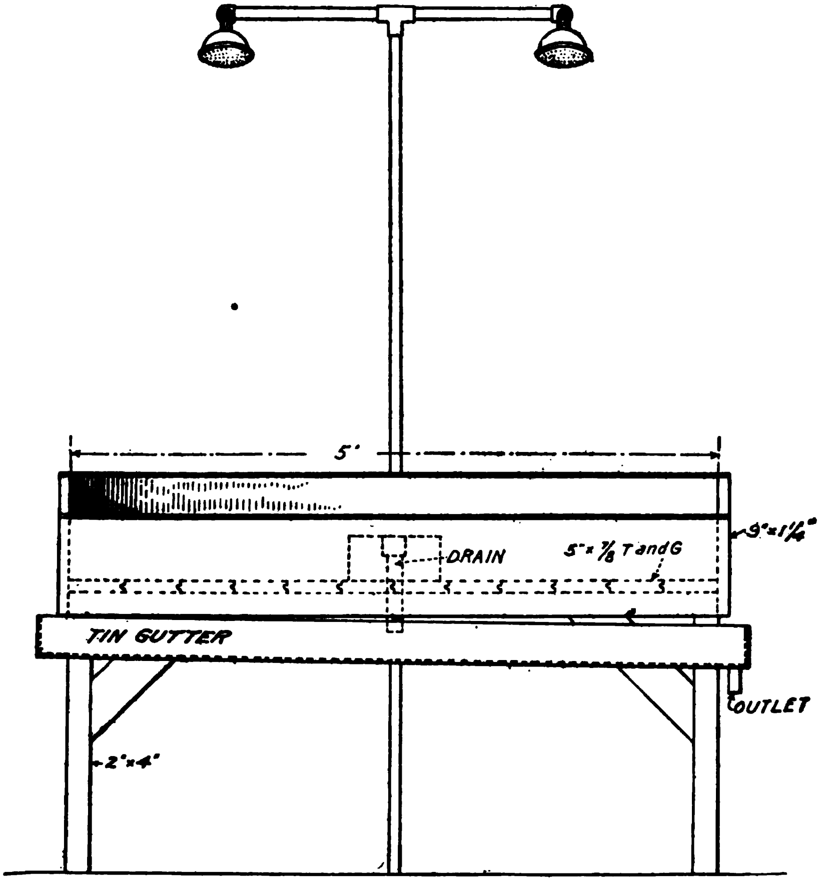


Fig. 4.—Front elevation of model.

satisfactory. Stretches of nearly level land should extend from the bases of the hills to the lakes. The land below the forested hill should be covered with a thin layer of top soil furrowed to represent cultivated fields. The parts of these fields adjacent to the stream and lake should be protected from washing by moss and shrubbery.

A double sprinkler should send with moderate force an equal rain-like spray over each hill. The spray should strike each hill in such a way that all the water will be drained into the corresponding stream. No water should flow down the rear slopes of the hills. One kind of sprinkler is made as follows: A water pipe is run up the wall behind the model to about 1½ feet higher than the summits of the hills. To the upper end of this pipe a "T" is attached, the arms of which run out about 1¼ feet on each side, and from the ends of these arms pipes terminating in sprinklers are run forward so as to bring the spray upon the proper parts of the slopes. A stopcock should be near at hand, so that the force of the water can be easily regulated within sight of the model. Rubber hose might be substituted for both the supply and the drainpipes and would reduce the cost. Baking pans perforated with a nail may be used as sprinklers. Great care should be taken to have the entire surface of the forested hill upon which water falls protected with moss, so that the soil can not be washed away. The water coming from the forested hill will be muddy at first, but will clear after running for a few minutes, and the mud in the water in the lake will soon settle. Erosion will set in upon the deforested hill and the land below as soon as the water is turned on.

The drain should be large and should be protected by a screen or trap so that pieces of leaves and moss can not get into it. A spiral of wire inserted in the upper end of the pipe will suffice. It is advisable also to have the water from the muddy lake pass through a clump of moss or other close sieve, to clear the water of some of the silt before it passes into the drainpipe.

White sand and pebbles and small goldfish or turtles in the clear lake will add another touch of realism and bring out the clearness of the water. Other ideas to add to the picturesqueness and instructiveness of the model can be worked in, such as a road running through the fields, bridges across the streams, and a little farmhouse or barn appropriately placed. The bridge across the muddy stream can be represented as damaged by floods, and the road on that side of the model muddy and deeply furrowed.

Materials for a model 5 feet square.

Lumber:
- 60 linear feet, 5 inches by ⅞ inch tongued and grooved flooring.
- 53 linear feet, 2 inches by 4 inches.
- 21 linear feet, 1¼ inches by 8 inches.

Other material:

1 bag of cement.
2 bags of sand.
1 barrel of rubble or small rocks.
5 pounds paraffin.
2 square yards of moss.
1 peck of top soil.
1 bundle of twigs or cuttings.
1 piece, 5 feet long, of ¾-inch iron pipe, both ends threaded.[1]
1 piece, 5 inches long, of 1-inch iron pipe, not threaded.[1]
4 pieces, each 1¼ feet long, of ¾-inch iron pipe, both ends threaded.[1]
2 single ¾-inch elbows.[1]
1 ¾-inch "T."[1]
2 sprinklers, similar to illustration (figs. 2 and 3).[1]
1 stopcock.
1 zinc or tin gutter 5½ feet long.
Pipe or hose to connect supply and drain with model.

---

[1] Other material may be substituted to suit a different style of contrivance.

ADDITIONAL COPIES of this publication may be procured from the SUPERINTENDENT OF DOCUMENTS, Government Printing Office, Washington, D. C., at 5 cents per copy

Walter Mulford

Strawberries, raspberries, gooseberries, grapes, plums, pears, quinces, and about every kind of fruit worth growing here, had their special friends; and last, though not least, vegetables of every name were brought to a high degree of perfection in the hands of members of this society.

In 1875 the State Horticultural Society accepted an invitation to hold their June meting in this city, as the guests of this society, which meeting was held in the opera house, on the 23d, 24th, and 25th of the month. At the close of the last session a very flattering vote of thanks was tendered this society for the very efficient assistance rendered by us to the state society.

But I must hasten to a close, or the gavel will drop before I have a chance to mention two important changes which occured later in the history of the society. On January 19, 1881, the following resolution was adopted: "That this society become auxiliary to the State Horticultural Society, and the constitution of the Adrian Horticultural society be amended to conform thereto, with the proviso to withdraw at any time by a majority vote of this society." By this action persons joining this society and paying one dollar become at the same time members of the state society and entitled to all it privileges. On April 14, 1884, the following resolution was adopted: "*Resolved*, That the name of the Adrian Horticultural Society be changed to the Lenawee County Horticultural Society," with headquarters in the city of Adrian, and that the annual meeting, and all special meetings for business, be held in the city of Adrian.

I cannot close this short history without a word of tribute to the men and women who early began this work, and whose influence is still largely felt in every department of horticulture. The majority have passed on over the river, and for aught I know are to-day basking in the sunshine on its flowery banks; but their labor here is not lost, as the interest still taken in this society fully demonstrates.

DR. W. OWEN.

Report Michigan Horticultural Society
1888.

WASHTENAW COUNTY POMOLOGICAL SOCIETY.

OFFICERS FOR 1889.

President—J. D. Baldwin.
Vice Presidents—J. J. Parshall.
Wm. McKreery.
J. D. Allison.
Secretary—Jacob Ganzhorn.
Corresponding Secretary—Emil Baur.
Treasurer—John Almand.
Executive Committee—W. F. Bird.
C. C. Clark.
J. D. Fuller.
B. C. Nichols.
Climatologist—Prof. W. M. Harrington.
Ornithologist and Entomologist—Prof. J. B. Steere.
Hygienist—Dr. A. B. Prescot.

Botanist—Prof. Volney Spaulding of Michigan University.

The society kept up regular monthly meetings, besides a number of extra sessions. During the winter we were favored with an interesting paper on the effects of forests on the climate and rainfall, whether or not effected by forests, etc. The paper was ordered to be sent to Secretary Garfield for publication, with report of the forestry convention held at Grand Rapids last winter. Prof. V. Spaulding interested the society with a paper on vegetable pathology. Mr. Erwin Smith of the department of agriculture, Washington, gave his researches on peach yellows, its early history, where first found, its spread and devastations it caused up to the present time, its appearances in the different parts of the country, etc. Mr. Smith illustrated his subject with photographic views of diseased peach trees, and the different stages of yellows. We have no yellows in our county as yet, and we do not look for any to come.

The spring and summer meetings were largely devoted to transportation of fruits by freight, including berries, shipping by express having proved inadequate, too expensive, and further made undesirable by a lack of proper handling in loading on board of cars. So far our shipments by freight have been confined from Ann Arbor to Detroit. A fruit car was fitted up for this special purpose, with shelving. The car was ready for loading during all the day, and such a privilege is highly appreciated by the fruit men.

We have a standing committee on transportation to attend to anything coming up incident to this business. The society has also spent much time in considering the feasibility of organizing a fruit exchange, but the matter has not yet taken shape.

Reports on the fruit prospects in the spring were very flattering. Results, however, did not justify the expectations. Young peach trees failed to set the fruit. Rains failed to come in raspberry time, though this crop was fair. The blackberry suffered more. There never was such a fall drouth known in the history of the State before. The want of rains left peaches very small, thus cutting a small crop smaller. Cherry and pear crops were light. The grape crop was good, though some vineyards suffered considerably from rot. The fall weather proved too cold for making grapes sweet, and therefore this fruit sold very slowly in the markets. The apple crop was good in quantity but ruined by the codlin moth. The bulk of this crop had to go to the evaporators and cider mills.

With the exception of the apple, all the fruits grown here will be considerably planted in this county in the coming spring. The peach will likely take the lead.

At our last county fair, there was a grand display of grapes, overshadowing all other fruits in appearance. It elicited more praise than any other fruit, the Niagara and Woodruff Red shining out supreme. The exhibit of pears was good. As high as twenty varieties were shown by single exhibitors. There were many entries of apples, and the specimens fair, but too wormy to be considered first-class as an exhibit. Our fruit men must not falter in a struggle with the codlin moth, or the excellence of the apple will be lost to us. There is another important subject that confronts us in this connection. It is the giving out of the favorite old varieties. We must either learn how to restore these to former perfection, or experiment with newer sorts. Probably the better course to pursue is to do both.

Exhibits of fruits in season at our meetings continue to be a pleasing feature to attendants. We also aften have flowers. Our meetings are now and then enlivened with reports by members on their visits to distant states, relating observations on fruits, etc.

JACOB GANZHORN, *Secretary.*

CLIMATAL EFFECTS OF FORESTS.

The problem of the effects of forests on climate and weather is not a new one; it has been discussed for upward of 300 years* yet in this long interval no universal agreement has been reached on the subject. The Germans are indeed entirely positive that in their country the effects of forests are very evident, and Herr von Bebber in 1877 formulated the unmistakable effects into sixteen propositions. †These propositions are:

I. The forest lessens the extremes of heat and cold without making any notable change in the mean temperature.

II. The forest air is always relatively damp, and hence the presence of the forest tends to the preservation, and somewhat to the increase, of the humidity of the air.

III. The tendency to precipitation, and hence the probability of rain, is increased by the presence of the forest.

---

*The oldest reference known to me is the order for forest police of Salzburg in 1524. See Günther, Grundzüzi der Geophysik, II., 242.

† As above, p. 246.

IV. The rainfall is increased, especially in forest-covered mountains.

V. The evaporation is decreased and especially when the ground beneath is covered by dead foliage it is very much decreased.

VI. The covering of leaves tends to prevent the rapid flowing off of water.

VII. Forests protect and preserve the natural springs of a territory.

VIII. The ground water held by the forests fills the soil beneath.

IX. The forest protects from floods and prevents the formation of new stream beds.

X. With extensive disforesting weather extremes become sharper.

XI. Disforesting brings with it increased dryness and summer drouths.

XII. The frequency of rainfall, especially in the summer, decreases with removal of forests.

XIII. Removal of forests decreases the wetness of the soil and the abundance of springs.

XIV. The removal of the dead leaves causes too rapid evaporation.

XV. The removal of the dead leaves promotes overflow of adjacent cultivated lands and this is still worse when leaves and trees are both taken.

XVI. The amount of water in streams becomes more and more irregular as forests are removed.

So much for Germany. In France, where the subject has also received very much attention, a similar list could be made out with one or two additional specifications. France is especially subject to destructive thunder and hail storms, and it frequently happens that well cultivated vineyards and fruit farms, which have been brought to a high state of perfection at the expense of much labor and money, are, at the very time they are about ready to furnish an abundant harvest, utterly beaten down and destroyed by a sudden, severe, local storm. The owner sees, in utter helplessness, the work of years and the support of his family swept out of existence, and perhaps five minutes will suffice to do the work of destruction. Hail-storms have naturally received very much attention in France and, though much that is of importance has been learned about them, the only thing so far that will help the cultivator of the soil is this rule that destructive hail-storms are much less common in forests.

By some writers the effects of forests are given still more importance. Marsh, in his Man and Nature, and in his wake many others have tried to show that disforesting may change the climate of a country completely, altering it from a fertile region capable of supporting a large population to a desert waste. As they read history, Palestine is undergoing this change and has almost completed it. According to some of them the change has already been completed in northern Africa. Carthage, they say, was in a fertile region. Tunis is now largely desert. The Syrtes were once good harbors to a fertile inland; the desert now comes down to the coast and its drifting sands shallow the waters of the Mediterranean far to the seaward.

But agreement on the subject is by no means uniform. The idea that disforesting may make a general and permanent change in the climate is hotly contested inch by inch, and the victory now inclines strongly toward those who believe either that no such change has occurred as a matter of history, or that if it has occurred, it is due to other causes than disforesting. The meteorologists of India are remarkably active, and they claim that in that country the results of disforesting are entirely local and subordinate. The Scandinavians have always been meteorologists, so much so that the ancient climate of their peninsula could almost be reconstructed from their myths. This interest in the weather there continues unabated, and some of the most eminent living students of the subject are to be found there. They claim that the results of disforesting are there entirely unnoteworthy. America is so new that it is not so much a question here as to what has happened as what will result from disforesting and reforesting. The subject has, however, already been much studied, but the conclusions seem various. Dr. Hinrich, the eminent meteorologist of Iowa, finds unmistakable evidence that in his State rainfall lines and forest outlines go together. It has been frequently claimed and almost as frequently denied that with the extension of settlement, and with it tree planting on the plains, increased rainfall and amelioration of climate have resulted. The question is not yet settled, but the balance tends to turn to the side of amelioration. Recently Mr. Henry Gauvett has attempted to show that no change of rainfall can be expected from change in forests.

I have stated as clearly as practicable the variations in conclusions in order to point out that the disagreements are more apparent than real, and that they result from not making a proper distinction—a distinction which I think we have only lately been in a condition to point out. This distinction is to be found in the three different elements of weather or climate.

One part of our climate or weather is of a general character, due to the inclination of the earth's axis, to the general character of the atmosphere, and, to a less degree, to the general distribution of land and water, mountain and plain over the surface of the earth. A second part of our climate and weather is the periodic, and more especially the daily variation of barometer, of thermometer, of relative moisture, of wind, and of cloudiness and precipitation. The source of these changes is to be found in quite as general conditions as the former, but the quantity of the changes is much more dependent on local conditions. The temperature on the average is warmest with us at 2 or 3 P. M., and coldest about 6 A. M., but the range of the change will be very different for different parts of Michigan, and even for different parts of Washtenaw county or of Ann Arbor.

The third element of our climate is to be found in purely local conditions. Elevation here plays a very important part. The weather of the east side of a mountain range may be very different from that of the west side. The weather of the deep valley may be quite different from that of its limiting ridges. On a still cold day in winter the temperature may change considerably with slight changes of elevation. In such weather the thermometer always stand higher at the observatory than in any other part of the city and between the observatory and the Huron river, half a mile north but perhaps 100 feet lower, we have frequently noted a difference of 12° or 15°.

Now of these three elements which would be affected most by local foresting or disforesting? Evidently not the general element. Our general weather is made up largely of large storm areas or cyclones followed by large quiet, clear areas or anti-cyclones, all traveling eastward with more or less regularity. These areas are usually first seen in the Rocky mountains or to the east of these mountains. Sometimes they come from the Pacific ocean or from Alaska. Very rarely they appear to originate nearer home. Their cause of origin and exact source are unknown but we are positive that they depend on general conditions, conditions of the whole earth or of very large areas. For instance two large areas of low barometer usually occupy, one the north

Atlantic, the other the vicinity of Behring's sea, and the cyclones often come from them. Again a large anti-cyclone usually lies over the central north tropical Atlantic just east of the African coast, and another varies in position from Mexico to our southern states, and the paths taken by our cyclones seems to depend much on these anti-cyclones. The positions, activity and motions of the great northern cyclones, the position and motions of the great semi-tropical anti-cyclones are undoubtedly due to general conditions, relative to the earth as a whole or to its general features of distribution of land and water. They cause the large features of weather and it is evident that they are beyond the reach of the comparatively small changes caused by man. Whether Michigan were covered with forest, or entirely cleared, would probably make no difference with them; their general features for Michigan would be the same. Indeed we may doubt if the foresting or disforesting of the entire United States or the presence or absence of the great lakes would make much difference with these general features.

There is however one element of a storm area which seems much dependent on the character of the territory passed over, and that is its intensity. A cyclone, in the limited scientific sense, is an atmospheric condition favorable to rainfall, but whether rain falls or there is only cloudiness without rainfall depends on the intensity of action in the cyclone and this intensity changes from region to region. Not even a cyclone can squeeze rain out of atmosphere in which sufficient moisture does not exist. Now it is a matter of scientific observation and of practical experience that forests are relatively moist, both because the roots and dead leaves tend to hold the water, preventing it from flowing away, and because the tree is a natural evaporating machine, through the thousands of mouths of which moisture is constantly pouring into an atmosphere not already too dry. Hence the cyclone finds in forest air the moisture it needs, and that of its functions which is most irregular and uncertain, viz.: that of precipitating moisture, is more probable over forests than over plains, and more probable over grassy plains than over deserts. This entirely agrees with Von Bebber's empirical conclusions III., IV., XI. and XII. In this too we also find one reason for the conclusions which relate the greater frequency of floods in regions which are disforested (conclusions IX., XV. and XVI). The rainfall being more frequent in forest areas is less likely to be so severe as to cause floods.

But it is especially in the perodic and local features of climate that the forest plays a valuable part. By the covering which it gives the soil the extremes of temperature are much reduced. Just as in the Artic regions they wear clothing to protect from the cold and in the tropics to protect from the heat, the clothing of forests limits that direct exposure to the radiation of the sun which gives us our hottest days and that re-radiation of heat into space which gives us our coldest nights.

Again the forest serves as a sort of break water to protect the residents in or near it from the action of high winds, and they serve as another sort of protector in a much more important sense. They protect and hold the water which reaches them, the shade of the trees protect from evaporation and it occurs but slowly except as this occurs through the leaves. Besides, the covering layer of dead leaves serves as a sponge to soak up and keep the water which reaches it, and still more to keep the water which passes into the soil beneath. Hence the conservation of moisture and that of springs in or near woods, and as they let this water escape only slowly and gradually, hence, also, the uniformity and persistence of forest streams, No one can understand what the latter means unless he has stood on the banks of a stream on the plains or in the treeless part of the Rocky Mountains during a rain higher up the valley. The bed of the stream is dry; a rushing sound causes the observer to look up the stream; the rain which has just fallen is coming down with a rush; it passes rapidly and in a few hours or at most a few days the stream is again dry. Compare this with the perennial streams of our own woodlands which fed by springs protected by trees, continue almost unchanged from season to season and from year to year. Moreover this sudden rush of water brings with it, in a region recently disforested where the ground is not yet protected by sod, an immense amount of silt, sand, gravel, and rock, which spread over and ruin the cultivated fields further down. These are the most familiar parts played by forests and are known to all thoughtful men. I mention them here to point out that they are features of local rather than general character, but that they are local does not render them limited in area or unimportant in character.

But the next feature to which I wish to call your attention is less familiar to the general public, and also, unfortunately, less completely worked out by professed students of the subject. The features of weather and climate, especially those of summer weather which most interest and affect those who draw their support directly from the soil, are due more to what are called "local storms," than to general storms. A good illustration of these storms is the sharp, quick summer thunderstorm, and the no less sharp and quick, but much more destructive first cousin of the thunderstorm, the tornado. These phenomena are not integral parts of a cyclone or storm area, but are only indirectly connected with it. They are generally connected with some unsymmetrical feature of a cyclone,* such as an arm put out to southward, or a brood of small secondary whirls like a hen with her brood of chicks. To these local storms the most of our summer rains are due, and in some parts of the world all rainfall comes from them. These are the phenomena too, which the weather-predicter in his central bureau at Washington or Toronto or London is least able to foresee. These storms generally run low and are, therefore, especially sensitive to local conditions. The hail comes from them, and thus we find in France the fact that hail storms are somewhat guided by the outlines of forests, as they lie low they will be more likely to be influenced by moisture preserved by forests, and the increased rainfall in or near forests is probably much more due to them than to an increase in intensity in the general cyclone.

But the action of forests on these local storms is by no means clear, and it is here that there is an opportunity for profitable study for every intelligent observer of nature. It seems that some kinds of local storms may be increased in intensity by the presence of forests. So far as that increase is rainfall it is favorable for Michigan, for a cloudburst in a forest need not result in a flood in the adjacent streams as it would necessarily result in open land. And may I be pardoned for calling attention to this line of study of local storms and local influences? The study of the general weather is cared for by the general government and by professed meteorologists. The local conditions are however of the greatest importance, and this should be cared for by the state governments. Hence the propriety of our local weather service, and in their work they require the assistance of, and can be aided by, every intelligent person. It is only by supplementing more general studies, by study in small regions, that we can now expect to make much advance in the knowledge of local storms, and these are of paramount importance to our farmers.

---

* The cyclone is an area of general low barometer and its name is due to the circulation of wind in it. Its individual character may vary from so slight an intensity that it is barely recognized by instruments and not at all by the senses, to as great an intensity as that of the West Indian hurricane. The tornado is a small whirlwind of great intensity, but is not a cyclone.

We can now perhaps see why there is such a general disagreement as to the influence of forests on climate. The chief effects being local in character they would be most appreciable when the local conditions are most favorable. For instance when the conditions were such that abundant moisture is generally present, the play of the forests would be subordinate. This is the condition of things on the Scandinavian peninsula, surrounded as it is on nearly all sides, and nowhere distant from large bodies of water. The clearing of the entire peninsula of forests would make but little difference in the supply of moisture. But in the continental position of Germany, especially more inland, the supply of moisture is less abundant, the change of temperature more excessive, and the conservative action of forests is more important. Again, the action of the forests would differ with latitude. In the tropics generally the greater uniformity of weather and the more extensive character of weather changes would make the covering of the soil of only very local importance, while in high latitudes, the slight variation in moisture and the general protection of the ground with snow would also tend to lessen the distinctive effects of forests.

It is only in middle latitudes that the effects would be important, and it is in continental positions that they would become most conspicuous. Michigan is in middle latitude, and she is well in the interior of a great continent. We may expect that she will prove to be quite as sensitive to the removal of her forest clothing as is Germany; and there is another feature of Michigan which may make us look forward with anxiety to her total disforesting. Considerable parts of central Michigan have a sandy soil; they are the so-called "pine barrens." They have the reputation of not being valuable for cultivation. What will they be when timber growth has been removed which now holds the sands together and protects them from the direct drying rays of the sun? There is some occasion for fear that their value may then become less than zero; that while they are now not without use, they may then become a menace.

MARK W. HARRINGTON.

Feb. 4, 1888.

Rhode Island Experiment Station Re
1901.

Walter Mulford

THE FOREST, ITS INFLUENCE AND MANAGEMENT.

FRED W. CARD.

FOREST INFLUENCES.

The wood-fire crackles in the grate; the flames leap merrily up the throat of the great chimney; the sparks dance upon the hearth, and the wood crumbles to ashes; the woodman's axe rings in the crisp wintry air as the forest falls to supply the need. Nature has been generous to provide this supply. Are we doing our share to perpetuate it? Will our children and grandchildren censure our memory for destroying their heritage?

Much has been written of the value of forests, some sentimental, some ill-advised, some pessimistic, and some of great value. Let us think well before we destroy the forest cover from the mountain side or the farm. Let us consider the advantages which it will bring and the inconvenience which may accrue when it disappears.

The benefit most commonly supposed to result from the presence of forests is that of increasing rainfall. This opinion has most frequently resulted from a comparison of the conditions of some large country at different periods of time far apart. If the country has once been productive and later becomes barren, the result is attributed to the disappearance of forests; or, if the reverse conditions hold, the forest is credited with bringing them about. Much of this assumption is without foundation. The forest is as likely to be a result of the conditions as the cause of it. Careful observations, set forth in meteorological reports, often fail to show any appreciable increase in rainfall due to the proximity of forests. In other instances such increase does appear, particularly at increasing altitudes above sea level. Topography and general climatic conditions are far more important factors in the production of rainfall than the presence or absence of forests. It is safe to assume that the much or little woodland which a man may maintain upon his own farm will have no effect in increasing or decreasing the rain which falls upon it. The storm areas which sweep across the country are often a thousand miles in diameter, and the rain which waters the farm may have come from very distant sources.

If the forest fails to coax a greater amount of rain from the clouds, it does not fail to make good use of what does fall. The water which reaches the ground may follow two distinct courses. Part of it may run away upon the surface, to quickly swell the streams and produce the spring or autumn freshet. Another part percolates into the soil, being held there to be used again by plants, or, passing downward, supplies the underground flow of springs and streams. The proportionate amount of these two factors is of the highest importance to the welfare of the farmer and of the adjacent communities. This proportion is determined by the topography of the region, the nature of the underlying rock, the character of the soil and of its surface covering. Of these only the surface conditions are within the control of man. No better surface conditions for inducing underground flow are to be found anywhere than those which the forest floor presents. Its irregularity, its hollows and hillocks, its mulch of leaves and its coating of moss, the loose, granular condition of the soil beneath, and the large admixture of humus near the surface, all tend to hold back the rain and afford it an easy entrance into the soil.

It may be said in passing that this large admixture of humus is one of the most important factors in rendering virgin soil so productive. It not only permits water to penetrate the soil more readily, but it also enables more water to be held. It furnishes the mechanical condition best adapted to plant-growth and least favorable to hardening or baking. The farmer may well take a lesson from the forest, and embrace every opportunity to add humus to his soil.

Removing the forest from the hillside may seriously reduce the flow of the stream which waters the farm or cause the spring at the foot of the hill to fail. Removing many such forests reduces the water-flow of the larger stream to which they all contribute, compels the manufacturer to abandon his water-wheel and substitute the steam-engine, or perhaps even to move his plant to another location where fuel and material are more readily available. Not only that, but the annual freshets are increased. The maximum floods each year grow higher, the expense for bridges, fences, and highways and the public taxes increase. Think well, then, before you sweep bare the hillside.

Water is lost not only when it runs quickly into the stream and away, but it is lost when the winds entice it from growing plants. This evaporation increases greatly with the increase of wind velocity. A forest on the side of the farm from which the prevailing winds come, particularly if that side be higher than the rest of the farm, will greatly lessen this loss. Nearly all soils furnish abundant water for the growth of the plants themselves, were it not for this waste. Oftentimes its reduction may prove more important than an increase of rainfall would be, and more feasible than the application of water by irrigation. The difference in evaporation from the valley of the upper Hudson and that of the upper Genesee has been found to be five or six inches a year, representing approximately the difference in the State of New York between a forested and deforested area. The importance of reducing the wind velocity is forcibly shown by experiments made some years ago by the United States Signal Service, in which it was found that, under the conditions of the test, evaporation in a wind of five miles per hour was 2.2 times greater than in a perfect calm, while in a wind of twenty miles per hour, not at all uncommon, it was 5.7 times greater than in a calm. Experiments made with evaporometers on the plains of Nebraska showed that during one of the hot southern winds, which often sweep over that region in mid-summer, evaporation three rods north of a wind-break was only twenty-nine per cent. of that in a situation exposed to the wind. In this connection the comfort of men and animals, as a result of protection from the cold winds of winter, cannot be so easily estimated, yet is none the less worth considering. Hence, consider well the wind-break effect of the forest before it is swept away.

The sanitary influence of the forest needs also to be considered. The benefit of evergreen forests in pulmonary diseases is well recognized. Sanitariums are a prominent feature of the Adirondacks and of other forest regions. Dust and disease germs are uncommon in the forest atmosphere and find uncongenial lodgment if present. Forest communities in India are known to escape the ravages of cholera. Troops are sometimes moved to such locations and the disease checked, even when it has gained a foothold. Similar observations are reported concerning yellow fever in our own country.

A still more important sanitary effect is that upon the health of cities deriving their water supply from flowing streams. Science has invented no better filter than the forest floor and the soil beneath it. Remove this floor and the filter is gone. The water rushes over the surface in ever increasing volume, carrying refuse and dirt, garbage and offal, to deposit the whole in the bed of the flowing stream, there to taint the city supply. Small wonder that medical authorities urge the maintaining of forest areas about the sources of such supply!

The forest possesses still another sanitary influence, in that it gives rest and recuperation to those whose minds grow weary in the round of life. This is often more important than we may think. Let him who doubts it drop the pen or the plow some afternoon when vexations have come thick and fast, when his brain is weary and befogged. Let him leave them all and stroll into the forest. Let the murmur of its leaves and the play of its light and shadow soothe his irritation and dispel his weariness. Then let him measure the health-giving power of the forest.

FOREST MANAGEMENT.

The object of forestry is to utilize to the fullest possible extent the product of forest land, and at the same time to maintain the conditions which render forests beneficial. Utilizing the timber is as much a part of forest management as is inducing the growth of trees and protecting them during their growth.

The important consideration of how to replace the trees when cut is known as forest regeneration. Two methods are available, the artificial and the natural. Artificial regeneration may be by means of seeds sown and covered by hand, or by means of planting trees. Both these methods are too expensive to be used except where no others will succeed. Manifestly on the open prairies they are the only methods available when forests are to be started on land where no trees now grow.

Natural regeneration is the more common method, and the one more practicable under normal forest conditions. It may be by means of shoots or by means of seeds. The former utilizes the vigorous shoots which spring up when most broad-leaved trees are cut. The resulting growth is known in forest literature as coppice. The method cannot be used with conifers, and not all broad-leaved trees can be depended upon to send up satisfactory shoots. Such shoots make a more rapid growth in their earlier years than seedling trees, but they generally attain their best development within thirty years and are not suitable for the production of large, long-lived trees. Coppice growth, therefore, is adapted only to short rotations and the production of such classes of timber as basket material, firewood, fence-posts, telegraph poles, hop-poles, etc.

In the regeneration of forests by seeds nature is again ready to help, for she contrives many ways in which seeds are scattered that they may find places to grow. The wind is ever ready to carry them, and naturally the trees which become most widely scattered are those bearing light seeds with some kind of appendage enabling them to be easily carried by the wind. Then again, many seeds, falling into streams, float upon the water to take root on some distant shore. Birds and squirrels also aid in carrying on this work, the birds by dropping the seeds from berries and fruits which they eat, and the squirrels by burying nuts just beneath the forest floor, many of which are never dug up and eaten.

A seedling forest may spring up from adjoining woods, or underneath the shelter of other trees. In the former case natural conditions can be depended upon to give a good stand only over narrow strips. The conditions are more favorable when the trees are grown under shelter-wood. The first essential in natural regeneration is an abundance of seed; hence, mother trees must be left to provide for this seed. Forest trees seldom produce seeds in successive years. The seed years may be two to five or even more years apart; hence, the forester must watch for and utilize them when they come. The second essential is a proper seed-bed. To secure this may involve thinning to admit sunlight and to cause more rapid decomposition of the forest cover in case this cover is too thick, in order to insure proper germination, and allow the young rootlets to reach the soil. On the other hand, a proper seed-bed may demand wounding the soil, in case the woods are already too open, so that grass is growing beneath the trees. Once germinated, the seedlings demand sufficient light, yet oftentimes need protection from too strong light and from wind and enemies. They also demand sufficient soil-protection to prevent grass and weeds from gaining a foothold and absorbing the moisture which belongs to them. Hence a proper leaf-canopy above or a sufficiently thick growth of the seedlings themselves to form such a leaf-canopy is needed. To provide for this, plants are sometimes used possessing no value in themselves.

A forest may consist of a single species, when it is known as a pure wood, or of different species, when it is known as a mixed wood. Pure woods are seldom found. While they are more easily managed than mixed woods, the dangers are greater and the practice is seldom advisable. However, mixed woods of few species are generally more desirable than those of many species.

When different species are grown together, the light conditions demanded by each become of paramount importance. Certain trees demand full exposure to the sunlight, and will not grow in the shade of other trees. They are known as light-demanding trees. Manifestly they must be ahead in the race or they fall out altogether. Generally trees with light and scanty foliage belong to this class, although there are some exceptions. The birches, pines, honey-locust, black locust, black cherry, ash, and chestnut belong here. Other species will thrive in partial shade and are known as shade-bearing trees. Among these are the beech, maples, hemlock, and oaks. If, then, light-demanding and shade-bearing trees are planted together, care must be taken that the former are more rapid growers or else that they are given sufficient start to enable them to keep in the lead.

Thinning becomes one of the most important operations in forest management. Here again the light conditions are all-important and must be carefully studied. It is well known that a tree which grows in the open field becomes broad, sturdy, and vigorous, beautiful to look upon but useless to the lumberman. In forest management just the reverse of this type is demanded. The boles must be tall and straight and taper as little as possible. To secure this the forest should be thinned but lightly in its earlier years until the trees have attained their principal height. Thinning may then be increased, and these tall slim poles will increase in size, making the type of tree most desired. By this method the annual layers of growth will be more uniform and the quality of timber better, because the tree grows less rapidly in its earlier years than it would do under normal conditions.

Nature must be made to do her own pruning in forest management, and, like all other pruners, her work will be more effective if done when the branches are small. When trees stand thick in their earlier years, the branches are killed out from want of light while yet small; hence no large knots remain to injure the quality of the timber. Statistics taken from the Black Forest as to the number of trees per acre growing in forests of different ages show the averages to be about as follows: at twenty years four thousand trees per acre, at forty years one thousand, at sixty years four hundred and fifty, at eighty years three hundred and fifty, at one hundred years two hundred and fifty. The number of trees per acre will need to vary with conditions of soil, climate, and altitude; but these figures may give a general idea of the great difference in number between young forests and old forests properly managed.

Many systems of cutting and regeneration are in vogue where forests are systematically managed. For the farm wood-lot or small holding but one need be considered, and that is the simplest, known as the selection system. In it trees are cut whenever they have attained their best development, young ones being allowed to take their places at once. Trees of little value are made to give place to those of greater value, the object being at all times to maintain and improve the condition of the forest.

The kinds of trees to be grown is a question of importance. Their rate of growth and their ultimate value both need to be considered. In general, those trees which produce valuable timber and produce it quickly are the ones to be sought. Perhaps for most locations the white pine heads the list. Basswood, chestnut, red and white oak, black cherry, locust, catalpa, ash and others need to be considered. The trees of least importance are those which are of value only for firewood when grown.

The profits of forestry are manifestly small. Land well suited to the production of farm crops can seldom be profitably used for forests, but there is much land which yields such meagre returns when tilled that if properly managed as woodland, the financial results would be better, and the indirect benefits of even more importance. The relation of forests to communities has already been discussed. In Europe many communities own forests from which substantial returns are obtained. The city of Freudenstadt, a city of some six thousand inhabitants, owns five thousand nine hundred and fifty acres of forest land, from which the yearly revenue amounts to from twenty to twenty-five thousand dollars.

This pays all city expenses and gives a bonus to each voter in addition. Baden-Baden owns ten thousand acres of forest land from which it secures a net annual revenue of nearly $3.50 per acre. Other forests not so long under proper management yield proportionately smaller returns, the best yields coming from those forests which have been longest under control. Not only may communities find forests profitable, but the farm wood-lot, properly managed, if confined to land least adapted to farm purposes, and especially if so situated as to afford a beneficial wind-break and aid in maintaining the supply of springs or streams, will always yield good returns.

from the cell it can be washed down with the hose and thoroughly cleaned so that his successor need not be exposed to disease.

As a means of securing fire protection as well as added safety against the escape of convicts, the wooden ceiling of the old building was removed and a steel ceiling substituted in the new block, extending over the entire corridors. The ceiling of the block itself and the central corridor between the backs of the cells is all of tool proof steel plate. The ceiling of the fifth tier balcony is of 3/16" soft steel plate, and the ceiling over the main corridors outside of the cell block of light steel plate. In the case of fire, which can now occur only in the garret, the fuel supply will consist simply of the roof trusses and roof covering, and the block is so protected by the steel ceiling that no difficulty would ever be experienced in getting the entire force of convicts safely outside. The moral effect of the steel ceiling, in discouraging attempts to escape is also a valuable feature.

The impression made by this block when compared with the adjacent one in the east wing, which was built on the same general design as the old block in the west wing, is somewhat striking. The object aimed at in the entire design is not primarily to give the convict luxurious quarters, but rather to provide a habitation consistent with cleanliness. When this object is attained the function of the engineer gives way to that of the Chaplain in raising the convict to the next higher level.

Walter Mulford

February, 1905

SOME FOREST INFLUENCES.

BY FILIBERT ROTH, '90, PROFESSOR OF FORESTRY, UNIVERSITY OF MICHIGAN.

The opinion that the forest exercises beneficial influence on the climate, and the distribution of water supplies is probably much older than the Christian era. There is reason to believe that Homer's pleas for the mountain forests were prompted by this notion. The same appears true of the story of Erichthonios who is punished by hunger for having felled a sacred oak in the groves of Ceres. Equally probable is the opinion that the mythological relation of nymph or deity and tree had for its object to stay the heedless destruction of the woods.

Rœssig in describing the politics of August I, (1586) of Saxony calls attenion to a clear appreciation of the influence of the forest on the well being of a country. Among other things he says: "Frequently the forest protects the food supply of a district. It protects the fields against the devastating (dry and cold) north winds, etc." Buffon 1739 says: "The longer a country is inhabited the poorer in forest and the drier it gets." In 1792 the administration of the Department Basses Alpes (Lower Alps) reported: "The clearing of the woods progresses, large parts of the mountain sides are bare, the smallest creeks have developed into torrents, and several communities have lost their harvests, herds and even their buildings by floods."

Humbold and other travelers brought together numerous observations from countries like Spain, Italy, Asia Minor, North Africa and Assyria where extreme conditions prevail today and where more or less authentic records fairly prove that great changes have taken place, which in most cases are described as partly or wholly due to denudation of former forest growth.

During the 19th century when the advocates of forestry especially of State forestry were pleading before the legislatures of the central European states, the beneficial influence of the forest on climate and waterflow, as well as its great economic value in producing timber, was and is today one of the stock arguments. And it is this great argument which has led to the first steps in forest protection and rational treatment in our own country, and has brought about the reservation of over sixty million acres of forest lands by the federal government and of millions of acres by different states. The influence of the forest then, whether fallacy or truth, has proven a most important conception in political economy.

For convenience we may divide the consideration of forest influences into:

(a) What are the influences usually ascribed to the forest.

(b) What are the factors which underly these influences.

(c) How much of these influences may we regard today as proven knowledge or fair inference, and what portions remain as open questions.

Generally the forest influences are treated differently by different men and in different localities. Generally, too, the difference of opinions in this matter is largely due to a lack of clear statement of premises. Frequently strong assertion without attempt of proof robs the reasonable portion of the claims of their power to cnvince. In addition, and this is especially true of the controversy of latter years, the opponents agree that the forest exercises certain influences, or has the power to do so, but disagree as to the actual amount of such influence and its importance in the household of nature. For it is here, as in so many controversies of this kind, the defender claims too much, the opponent allows too little and neither appears to notice that it is the proverbial last straw which breaks the camel's back. But in forest influences more than in many other similar cases it is the small additional help which the forest gives which counts for so much. A mere handful of straw checks the "blow-out" of sand in your field; a light brush shelter checks the dune; a light brush cover protects the seedling plants against the killing wind and sun; the 90 degree F. in the sun are painful while the 80 degree F. in the shade of a single tree are quite tolerable, or even pleasant. It is the last few inches of our last spring's flood which changed a "high water" to a flood and cost Michigan millions of dollars in property. Similarly it is usually the last few inches of low water stage which change the conditions from power enough to run the mill to a condition of shut down. The crops of last summer in this vicinity did not suffer because there was no rain, for such was not the case, they suffered because they had not quite enough. A bit of protection against the drying winds might easily have remedied this.

Ordinarily and originally, forest influences were supposed to consist of beneficial modification of climate and water flow, though even in the earliest expressions the beneficial action of forest on soil and the ability of the forest to produce a valuable crop on poor lands, or lands not suited for fields, was clearly added or involved. Accordingly we may say that it was supposed that:

The forest modifies the climate, by increased rain fall or precipitation generally, by equalizing the temperature, making a country cooler in summer or warmer in winter; and by checking the influence of wind and storm.

The forest regulates the water supply, producing a condition of more water, less flood, steadier stream, and more soil moisture. In this way it was believed that the forest makes the land more hospitable, pleasant and healthful, and assists agriculture, navigation and manufacture.

And it was also held that the forest improves any soil, and its help is necessary on poor lands to produce any crop at all.

While the form of this belief has been modified and the stress is laid more and more on the things which may be proven or at least fairly inferred, the above three points still cover the matter of forest influences.

Formerly it was chiefly the increased rain fall which made the forest appear important to the state. Today it is realized that its value in the regulation of water storage and water flow, and its power to improve poor soils and to utilize the poorest of soils, amply justifies the care which the people of nearly all civilized states bestow on the protection, improvement and extension of the forest.

For centuries the claims of forest influences were based on observations and interpretations of extreme conditions. The misery of Asia Minor, the aridity of the lands of Babylon and Nineveh were ascribed to timber denudation. But about the middle of the eighteeth century, scientific men no longer content with these unproved assertions demanded exact study of this great question and the principal factors underlying the same.

Stations were established in France, Germany, Austria, Sweden, to study forest influences. These were usually double stations, one inside of the forest, the other in the open field. but in some cases regular "radial stations," or series of stations were established to note just how far the influence of the forest might be felt. The observations were mostly according to the programme of Regensburg and involved: Temperature of air and soil, rainfall and humidity. Generally the study of water flow and evaporation which were also included in the programme required special methods and facilites.

After half a century of observations it is fair to say that in the old settled states mentioned and as far as these observations go, there falls as much rain and snow on the open fields as in the forest, and the air in a box (properly shaded) hung up in the open field is no warmer than the air in a similar box similarly shaded in the forest. That the shaded air in the forest should be as warm as the non-shaded air over the open field was never claimed, and the results seem to indicate that the real and measured difference between the air in the forest and that outside of the forest amounts to about the difference between the temperature in shade and in the sun, disappearing, of course, during cloudy weather and at night.

Similarly the air in the German forest is generally found no more humid than the air of the neighboring field.

The study of the waters of the soil and streams which were made to ascertain the influence of the forest did not lead to results at all satisfactory. Their interpretation was usually based on premises which were by no means beyond dispute. The measurement of two streams, one from a heavily wooded, the other from a poorly timbered basin, might show considerable differences, but usually peculiarities of topography, natural and artificial drainage lines, rock and soil conditions would make the results seem doubtful if not valueless. For this reason experimenters like Wollny and Bühler long ago conceived the idea of subjecting this entire matter to experiment. They used large boxes filled with earth of definite uniform quality and stocked some of these with miniature forests of small size trees of different kinds.

Before discussing the results of these experiments it will perhaps be well to consider a few fundamentals which enter into the study, and for which a simple illustration is here repeated.

If we take a table, prop up one side to represent a hillside or slope; pour water on this table with a sprinkler to imitate rain, we see that the water runs off about as fast as poured on, the faster the steeper the slope. Now this is exactly what happens on a bare rocky slope and very nearly what happens on a steep slope where the ground is hard and bare. We have here nearly all of our precipitation in the form of "surface run off."

If now we cover the table with a six inch layer of earth and repeat sprinkling, taking care not to sprinkle too hard, we note that at first nearly all the water sinks into the soil. Soon however we have little rivulets which gather into larger ones and there is again a surface run off, but restricted to certain drainage lines or streams. But soon there is a gathering of the water which has soaked into and through the layer of earth and is pouring into little streams flowing along the surface of the table itself, but underneath the layer of earth. This is our "underground run off." If now we stop sprinkling, the surface run off stops quite promptly, but the underground run off continues for hours. The layer of earth forms a storage ground for the water in which the waters slowly gather and form into underground streams whose flow continues long after the sprinkling or precipitation ceases. It is evident that the deeper the layer of earth the more water it can hold. Also that the softer the earth the easier the water can soak in and the more will soak in and conribute to the underground stream instead of running off at the top as surface run off. It is clear that this experiment reproduces what is going on all over the land.

If now we resume the sprinkling, but sprinkle with more force, we see the water gathering in the surface rills, carrying off more or less of the soil, and thus gradually washing out or carving gullies which grow in depth and width, the faster the water flows and the more water is supplied. Soon these many gullies help the surface run off so much that but little soaks into the soil, doubly so since the harder sprinkling also tends to pack or harden the general surface of the layer of earth.

But this again resembles what goes on all the time on the earth's surface and thousands of acres of our western "brakes" and "bad lands" have an appearance as if they had been carved chiefly to illustrate this phase of soil physics.

It is especially interesting at this point to note how the trouble itself increases the power to do mischief. The more the land is carved, and gullied, ditched and plowed, the swifter the water runs off and the more carving or eroding it can do.

If now we cover the layer of earth with moist cotton batting, or some other similar material, we find that the soil does not erode as it did before, and also that it does not compact by the spray of water, but that again there is an ample soaking in of water, an underground run off.

But there is another important fact developed, namely that this cover of cotton batting hinders the surface run off very materially and thus gives the water all the more chance of soaking in. That a cover of growing grass or other vegetabtion could do the same service is at once apparent, and it is at this point where the influence of a live vegetable cover enters into the problem.

That there is a certain loss of water by evaporation throughout this experiment, and that this occurs in nature during every rain as well as at all other times is self evident.

Generally then the water precipitated as rain or snow is either evaporated at once, runs off at the surface, or soaks into the ground and is there stored and slowly finds its way into spring or creek as underground stream. This storage of water in the ground, which, to man is one of the most vital phenomena is, as far as our experiment indicates the greater, the more water offered, the more gentle and even the sprinkling or precipitations, the softer or more accessible the soil and the thicker the layer in whcih storage can take place, and the slower the surface run off, either through lack of fall of ground or through actual obstacles, such as rough surface, quantities of debris, or growing plants.

Returning to the experiments of Dr. Wollny and keeping in mind the foregoing it is interesting to know that the results of these experiments which well deserve to be called final and conclusive, fully agree with the above conclusions and differ only in so far as a live vegetable cover, whether grass or forest, differs radically from a lifeless cover assumed before.

Briefly some of Wollny's results were as follows:

1. The erosion is hindered by a vegetable cover. At an angle of 20 degrees there is over thirty times as much erosion or material washed away per square foot from bare soil than from the same soil covered by a sod of growing grass. Since erosion depends upon surface run off, the above is also a measure of this run off.

2. The soil under a cover of trees is no moister than the soil of bare land. A large average gave results indicating that the soil covered with the miniature forest was even dryer.

3. The forest litter if only one inch thick protects the soil against evaporation of water, so that bare soil evaporates three to five times as much water as soil covered by such a layer of litter.

4. The percolation or soaking of water in and through the ground was not helped by the vegetable cover, but was even hindered.

5. There is much more evaporation of water from land covered by a vegetable cover than from bare land and the forest cover in this respect is worse than a short lived cover of grass.

The forest tree is a consumer of water like every other plant, and the faster it grows and the thriftier it is the more water it needs and uses and sends up into the air as vapor. That this evaporation consumes heat and tends to cool the atmosphere is a simple matter of physics.

Years of careful, well controlled experiments demonstrate then that any live vegetable cover, but notably a forest strongly influences the factors which determines water storage and water flow. The run off and with it the erosion is reduced, and thus by far the most important factor in the entire process is affected in favor of water storage.

Comparing now the conditions we actually see and meet in the forest with the conditions of the experiments it is interesting to note that the experiments are quite fair, but that some very important conditions, evident in nearly every good forest and especially in our wild woods, are not well reproduced in the experiment.

Examining the wild woods from this standpoint we see:

A collection of plants 60 to 100 feet tall forming a gigantic brush-shelter on huge columns, with the ground peculiarly uneven, strewn with debris and often densely covered with the smaller growth of shrubs and young trees.

The soil as well as the layer of air fifty or more feet deep is shaded. On a hot sunny day this soil and layer of air are affected as things in the shade and not as things in the open, so that they are cooler by several degrees, a condition which effects plants and animals in a marked degree, and also diminishes the shelter capacity of the air.

The air is quiet. This huge brush shelter, like any artificial shelter of the same size and quality, retards the movement of the air. The effect of a hot, dry wind is lessened, the cooler air stays, the soil remains moist, the sensitive kinds of plants survive.

In winter time, the sudden thaw, nearly always a warm wind with rain, is checked by this huge shelter and while the snow on the prairie is fairly "eaten" by the Chinook, the snow of the forest is protected and holds out much longer, often but a small part disappearing with the thaw. That this affects high water and the flood is clear. While the snow on our field is piled up along the fences and in the gullies as if made ready for a rapid surface run off, the snow in the forest is distributed evenly and is protected against wind and sun alike.

The soil is uneven. Every stump and tree is on an eminence with depressions between. To be sure, this, as several other points very with soil, lay of land and even with species. But generally the soil is uneven and in most of our Michigan flat land woods one can see large amounts of snow or rain water stand in puddles gradually soaking into the ground without any marked increase in surface run off, and consequent flood or high water.

The soil is softer in the forests than on bare land such as prairie, pasture or long time burned slash lands. This particular feature has generally escaped the experimenter and yet any one at all familiar with the woods has observed the difference. Live and decaying roots are met everywhere, and often form 10% or more of the upper one foot layer of soil. All through the soil there is an abundance of vegetable matter and a constant working over of materials by bacteria, by higher plants and animals. That the rain water follows the many channels of decaying roots and finds it easier to soak into such mellow forest soil appears fair inference, in spite of the failure of Wollny to find this under his small miniature forests.

The soil is protected by a mulch of decaying leaves. Exceptions to this occur, but they are restricted to peculiar forms of forest, arid regions or localities where man and fire have begun their work of "improvement."

The value of this mulch is well brought out by the experiments referred to and is apparent to anyone. Under the mulch the material is damp even weeks after rain.

The soil is frequently free from frost and accessible to water in winter when the soil of the fields is frozen solid and therefore impervious. Large quantities of debris, decaying logs, limbs and twigs cover a goodly part of the ground in our wild woods. All this material soaks up water, holds water better than the soil, offers mechanical resistance to the run off of water, and adds to the shelter furnished by the forest.

A small shower in the forest barely reaches the ground, of all the water precipitated by a half hour's shower of moderate force probably not 50% would ever reach the ground. Rain gauges under trees in experiments have recorded 20-50% less water than others located near by but outside of the forest. But evidently such figures have little value, for in a long continued rain o fa week's duration this loss is practically zero, while in the half hour shower it may be near 100%.

A heavy rain fall of four hours in a forest "wets things down," but unless it is steep slope country there is no rush of water in the little creeks. A rain of the same character here about Ann Arbor transforms the little streams like our Mill Creek into a muddy torrent, in which hundreds of loads of the most valuable soil of the farms are sent into Huron river and thus permanently lost.

A three days rain makes the Brazos river at the Double Mountains in western Texas an impassable yellow torrent. This flood subsides in about the same number of days so that the teams camp and wait to ford. A three days rain on the upper Wisconsin does not swell the river. But high water on the Wisconsin river is not a five days affair but can be depended upon for two months log driving or rafting.

The fact that the forest materially and beneficially affects the soil is no longer disputed. But while it is one of the most valuable features and one of great immediate economic importance, a feature worth many millions of dollars every year, yet it is usually left out of the consideration of forest influences.

The action of the forest in this direction may be summed up about as follows:

The forest trees draw up the mineral salts, serving as plant food, from a greater depth than corn or wheat, etc.

The forest like the good farmer returns to the soil nearly as much as it takes of this plant food and spreads it every year over the ground in shedding its leaves. The forest furnishes ample vegetable material to keep the soil in fertile condition, keeping it more moist and mellow. By adding this organic material the forest encourages bacteria fungi, insects, etc., which help in working the soil and improving its condition, hastening even the disintegration of the mineral constituents. Keeping the soil more mellow the forest makes the soil more pervious to water and thus also improves its moisture conditions.

The forest protects the soil against erosion, against sun and wind, all recognized enemies of soil fertility.

While this reasoning seems of little importance to the farmer in Iowa, located on the richest of land, it is of great importance in our Lake State pineries and in the vast stretches of poor sand along the Atlantic and Gulf. The capacity of the forest to use and improve lands not otherwise of value will mean millions of dollars per year to our Lake Region alone and offers the only reliable means at present to utilize millions of acres of land denuded waste and unproductive for many years past.

If now we ask ourselves: What do we know concerning the influence of the forest; what may we fairly infer and what is still doubtful ground, it is clear from the foregoing fragmentary statement that the strong belief in these influences on the part of the people at large and especially our western people is quite well based.

Demonstrated experimentally; fully borne out by all careful observation, quite generally conceded and commonly applied in practice is the fact that the forest trees hold the soil, prevent erosion, and retard the run off of water. The common use of willows along dams and dikes, the cover of steep slopes with alder and other forest growth; the cover of Alpine slopes by the French government all indicate the general agreement on this point. Similarly the gullying of probably over 10% of all upalnd farmlands of Mississippi clearly prove the opposite or the effect of denudation, and the same is true of thousands of acres of land washed into gullies right here in southern Michigan.

Equally well substantiated and for centuries known to the forester and extensively employed in the agriculture of certain mountain regions is the fact that the forest maintains and improves the fertility of the soil and is so far the only reliable agent to cure and improve certain classes of run down lands. Equally well substantiated is the influence of the forest in moderating the effects of winds. This too is a matter of simple and especially of late extensively employed on our western plains. In Manitoba it is now claimed that a shelter belt protects a crop of wheat noticeably for a distance of fifty feet for every foot in height of the trees.

Similarly it is not disputed and is generally observed as well as measured that the flow of prairie streams is radically different in character from that of streams from timbered areas of about the same topography The extensive and faithful observations of the U. S. Geological Survey amply demonstrates this fact—that flood and drouth regularly alternate in the streams of prairie and arid land districts, while the streams from timbered areas present a more uniform flow and normally lack the mischief bringing extremes.

To the above hundreds of general observations might be added. Perhaps no place in the world was better suited than Michigan to supply valuable information on this point. The southern countries were largely swamp-dotted forest of which the surveyor 100 years ago stated it was unfit for human habitation or settlement. Ague was common; corduroy roads were universal. The clearing of the land, letting in wind and sun, was the simple method of drying up our land, for no one would seriously argue that if the forest had been left intact, the few ditches and lines of pigmy tiles would ever have made any impression on the moisture conditions of this wilderness. At the present time, every year miles of corduroy road are abandoned and thousands of acres of swamp are changing into plough lands without tile or ditch.

Concerning the influence of the forest on the climate particularly on temperature and rain fall, there remains great difference of opinion. The matter is still an open question. As has been pointed out the stratum of air in the forest and with it the soil and the plants enjoy the shade of the huge brush cover; of this layer it is fair to claim what has been stated above, namely that in sunny weather the forest air and plants and soil enjoy the temperature of the shade instead of the temperature in the open field or prairie. That the evaporation of water from the trees consumes heat and being greater than that of a prairie area, would tend to cool the forest and air about the forest is beyond dispute. That this influence is of value and felt especially by the more sensitive plants and animals is beyond doubt, but that it should make itself felt in the general climate of the region must remain uncertain and is certainly not a proven fact. And plete removal of all forest cover of Germany, for instance, would remain without appreciable effect on the temperature phase of its climate. How much more this is true of arid and semi-arid forested regions one needs but to think of parts of the Rockies and the west.

As to the rainfall we are still where we were fifty years ago. The difficulties of exact measurement alone involve sufficient error of observation to probably obscure the influence which the forest may have in this direction. But while there is nothing proven, nothing generally conceded, it is difficult to give up the thought of some influence here. A local shower here in the Lake Region may well be supposed to precipitate some of the moisture evaporated from lake, swamp or forest of the neighborhood. If this be true, then water storage, extensive evaporation from forest areas should be credited with at least a part of our local showers and thus the forest be credited with some influence on precipitation. And there certainly is much probability in the suggestion of Judge X, of Alturas, Cal., when he said, while watching the clouds coming from the west and fading into the endless blue of the Nevada desert, "Suppose these mountains (Warner range) were entirely bare, don't you suppose that this continuous sunshine would heat them until the clouds would all pass over without shedding a drop of water?" This same thought is expressed by Humbold in his Kosmos, and is a thought quite universal among people who have had a chance to compare.

But, it will be asked if so in many essential points of forest influences are thus proven and conceded. why is there so much controversy?

The reason is this: These influences are clear and beyond doubt *qualitatively,* but not so *quantitatively.* "All true enough, but it does not amount to anything," is the common phrase of the opponent. And here lies still the cause of dsagreement. Millions of observations on rainfall, on temperature and humidity of air and soil in forest and field have done practically nothing to demonstrate any marked influence in this direction.

Experiments, observations and measurements have demonstrated that the forest improves the soil and affects water storage and water flow. As to the improvement of the soil controversy has ceased. Even though the matter can not be stated in simple figures we are agreed that it is enough to be of enormous economic importance. Governments and private people alike are willing to undertake large operations of restocking poor land with timber on the assumption of the quantitative value of this form of forest influence. As regards water storage and water flow we are still more or less disagreed. While exact experiments on a small scale demonstrated qualitatively the relative value of the different factors entering the problem and while they thus prove the important influence of the forest cover, it appears to be beyond these experiments to furnish mathematical expressions which could be applied to the field. This is but natural. The problem on the swamp-dotted flat pinery sands of the Lake Region can in no wise be compared to the problem of the mountain districts of Pennsylvania or the West. The amount and distribution of precipitation, topography, soil, rock, prevalent winds, general temperature, species of trees and consequent character of the forest all tend to complicate this problem.

Measurements of streams of well- and poorly forested basins abroad have not helped in this matter. Measurements of the Ohio, Wisconsin and other streams, and the attempt to prove historically a change for the worse in their flow, flood and low water conditions were but little more satisfactory, though to one who has lived through these changes, has seen the Wsiconsin change from a navigable river into its present condition these changes are powerful argument. The measurements of prairie, arid land and forest streams by the U. S. Geological Survey in our country have done more and have at least pointed out even quantitatively the wide difference between the character of the flow of these streams. An address by J. B. Lippincott of the Reclamation Service of the U. S. G. S. at the Forestry Congress at Washington, Jan. 1905 brought out these facts most convincingly.

But when the question is asked: *How much difference* will it make whether we go on and clear our lands or leave 25% of the area in woods? we are still without a reliable, even approximately accurate answer. That it will make a difference, we all know and concede; but how much we do not know and probably never shall. The complications are too numerous, the factors too large. A few have been indicated above. A river basin, today covered by timber, but cleared during the next five years, will not take on a settled water storage condition at once. For years the benefit of a forest cover will continue to be felt. In many places, such as parts of Michigan, Ohio and Indiana, the clearing and partial drying of the land was a benefit, was necessary to make the land hospitable. So the question is one of immediate local conditions.

For southern Michigan it is safe to say that by denudation of forest by cultivation of land, by ditching and drainage, we have reduced the water stored in the land and have increased the surface run off to an extent which has affected the general welfare of our people. By the same means we have encouraged erosion which has cost us thousands of acres of good land by gullying and has injured by surface washing many thousands more. We have encouraged the sweep of drying winds and thus lost in our agricultural crops sums which no one is in position to estimate, though the loss is universally acknowledged and its immediate cause conceded. The individual farmer, the business man of the town and city, the railway, the town, county and state all are losers, and the latter the greatest loser of all. Its loss counts up by millions of dollars per year, and not merely for today and tomorrow, but for all time to come. The individual can not and will not correct the trouble, the state alone can. Will it see its opportunity and its duty?

surroundings and human associations ; both exerting a powerful pressure on character. Of human associations, the family is the most influential; but its partial decay has thrown the proper function of the family upon the school, hence the demand for an education having primary reference to character. Such education may be obtained, in a measure from all subjects, but most readily and effectively from literature and history. This explains their sudden and unprecedented prominence in the schools and in educational discussions. Literature is the most efficient in developing the consciousness and training the character of the individual as such; but for this very reason its tendency is subjective and cosmopolitan rather than objective and national. The tendency of history, on the other hand, is in precisely the opposite direction, so that literature and history constitute, in this respect, the educational complements of each other. The content of history, as of literature, is ethical: through it the individual enters into the experience, the ethical heritage, of his race. But unlike literature the ideals embodied are objective and the inspiration is drawn from deeds, not words. History moreover, is distinctively social: its function is the development of character with reference to life in organized society. It is the foundation of patriotism and good citizenship; it diffuses the ideals which unite the people into one nation; it leads to an understanding of the present organization of society ; it gives a clear and sane outlook upon the future, combining conservatism and progress; it causes the individual to feel himself a part of a larger social whole, an instrument of a Higher Power.

Is it asked how much of this may be accomplished in high schools? I would answer, all of it. History cannot be well taught, as it is in many schools, without accomplishing, in some measure, all of these results, even though not one of them is consciously present to the teacher's mind. It is true in school, as elsewhere, that the things we do best are often those we think least about. The best teaching is done when the teacher is eliminated and the mind of the pupil confronts the facts of the universe and of history, face to face.

EDWARD VAN DYKE ROBINSON

CENTRAL HIGH SCHOOL,
St. Paul, Minn.

Walter Mulford

THE PLACE THE SUBJECT OF FORESTRY SHOULD OCCUPY IN HIGH SCHOOL INSTRUCTION

DURING the winter which has just passed I delivered a lecture for Dr. Charles DeGarmo, of Cornell University, on the place forestry should occupy in high-school instruction. The class consisted mainly of teachers, and the course, of which the lecture above referred to was only a very small part, consisted of lectures by various educators on high-school instruction.

At first thought the majority of well informed individuals would say that forestry deserves no place in the already overcrowded curriculum of the high school. After I had made my position clear the opinion of the class seemed unanimous that some forestry, at least, should be taught in connection with, or as a part of, geography in high schools. A few at first argued with reason that if forestry should be taught, agriculture and a host of other subjects deserve a place. These persons, however, failed to realize the important rôle which the forest plays as a geographical agent in checking the destructive forces of nature, modifying the nature of the earth, and in molding the nature of the occupations of its people.

Forestry may be classed in two ways—first as a profession and second as a subject of general interest about which every well informed citizen should know something. In the first case the nature of the instruction should be detailed and technical and should cover a period of at least four years. This sort of instruction belongs to schools of forestry and agricultural colleges. There are already two schools of forestry in this country —one at Cornell and the other at Yale University. There are many such institutions in Europe. It is to these schools where a student must go in order to become a professional forester. It is in such institutions that a student is taught how to properly form, tend, and utilize a forest. In addition to learning how to care for forests, he learns also how to survey, construct wagon roads and logging railroads, operate saw mills, etc. He is, in other words, a forest engineer.

In the second case, for the acquisition of knowledge of a general nature relating to the forest which every man and woman should know, the high school is the place. All are agreed that in case it should be taught at all it does not belong below the upper grades of the high school. It is also so that a very large proportion of our high-school graduates would never acquire such a knowledge unless they get it in the high school, because many of our high-school graduates never go to colleges and universities and because many of our colleges and universities do not offer instruction in many of the most important subjects. There is no subject, for instance, of more general interest and of more importance than ethnology, yet how few even of our great universities offer instruction in this subject and how few of their graduates know even the names, to say nothing of the natures, of the peoples who once inhabited America.

It is not my intention to suggest the addition of another subject to the high-school curriculum. It should be given, however, the place in physical and commercial geography to which its importance entitles it. It is very easy for a man to exaggerate the importance of his specialty. Few doubt, however, the importance of forests. As compared with Europe, general information on the subject is wofully lacking throughout this country. Very few know the meaning of forestry. Arbor Day celebrations have done much to stimulate an appreciation of trees but these celebrations are often farcical, if not misleading, in nature. A song is sung, poetry recited, and then a few trees, often only one, are carelessly stuck in the ground, often in the very place which should be left open. A very small proportion of these trees live, however. "O, Woodman, Spare that Tree" is sung. A forester never hesitates to cut a tree if it is ready to cut, but he always plants more and plants them well. Aside from this question of Arbor Day, an institution which has been adopted in many parts of the world and which will do lasting good if properly conducted, why should forestry be taught in high schools? First of all, every great movement in this country must have popular support back of it. Our people must be educated to a point where they will know the advantages of a forest cover and the meaning of forestry. When this occurs the future of forestry is assured. The main cause of reckless, wasteful forest destruction in this country is ignorance. It is certainly one of the functions of the public school to overcome this difficulty. It is not necessary to introduce forestry into the public schools of Germany because forestry is born and bred into the body of every German. The proper care of forests is there a matter of course. Secondly, why does it deserve a place in high-school instruction in connection with geography?

I can only mention, in passing, the importance of the commercial side of the question. Think of the great lumber industries of the North, South, and far West, of the hundreds of thousands of railroad ties, telegraph poles, and bridge pilings, of the immense amount of wood used in construction for houses and fences and the hundreds of industries which make use of it. Think of the rubber forests of the tropics, the naval stores industry of our South and maple sugar of the North. Think of cork, camphor, rubber, wax, dyes, medicines, and a host of products yielded by the forest in various parts of the world. The young man about to enter business should, in fact must, know something of these products. It is of interest to note in this connection that two mahogany logs sold for $5200 in Liverpool last year. These logs came from Africa, and were purchased by an American.

It is not, however, on this side of the subject that I lay special stress. Although this is a part of commercial geography and although every young business American is eager to learn of the products, industries, and occupations of every country, the side of the subject which relates to the influence of the forest in molding and beautifying the earth is of much more importance and much more in place in the geography of the common high school.

There is too little space for me to define it except in a general way.

1. The forest is a soil former. Vast areas of swamp lands

consist of the black decayed remains of the forest. One tree in the tropics called the mangrove grows in salt water on the edge of coral islands. So much land is wrested from the ocean by its aggressive growth that it is often called the "landformer." The same is so of the willow, that Cinderella of trees, in northern latitudes. Trees cause the disintegration of rocks. The acid produced in the decomposition of organic matter causes the rock to crumble into soil. The tips of roots dissolve their way through soluble rock. In coral islands large trees may be seen growing out of the solid rock.

2. The forest is a soil improver. A virgin soil is a soil rich in leaf mold. The roots of trees penetrate to the deep layers of the soil and secure rich mineral matter, which is deposited on the surface with organic matter in the form of leaves and sticks. The only way to bring virginity back to a worn-out soil is to grow a forest on it.

3. The forest is a soil fixer. Erosion is the wearing away of rocks and soil by wind and water. Shifting dunes, sandstorms, landslides, and avalanches are prevented by a forest cover. The mass of roots holds the soil in place. Many countries have been rendered inhabitable by the planting of trees. Whole villages have been destroyed in Europe by landslides and shifting sands. This has been prevented by forest planting.

4. The forest is a flood preventer. The flow of water is retarded by the roots and litter of the forest floor. A flood to be conquered must be attacked in the hills of its source where its forces are scattered and easily controlled. The way to conquer it is through the agency of forest growth. The forest imparts a regularity to the flow, so that there is less high water in wet seasons and less low water in dry seasons. This means much to industrial establishments along the banks of a stream depending upon its flow for power. Snow melts slowly in the shade of the forest.

5. The forest is a windbreak. Nothing is more destructive than a hot dry wind. It blasts and levels crops. It parches the ground. Nothing is more wearisome to man and beast. Nothing is more grateful than the shelter of a belt of trees.

6. The forest beautifies the earth. The ideal country is the one in which there is proper mingling of forests and fields—forests in the mountains and fields in the valleys. A treeless country is distressing and monotonous.

7. The forest is a sanitary agency. Malaria follows in the wake of forest destruction. The purity of forest air is proverbial. It is a resting-place for busy brains. It is the source of good, pure water for many large cities. The war department is planting Eucalyptus trees in Havana province to prevent malaria and yellow fever. This has been done elsewhere with considerable success, especially in Italy and Algeria. The Landes of France was once a pestilential swamp. Since the planting of pine trees it has developed into a health resort. A forest occupation is healthy. It produces strong, broad-chested men. Would that a large number of our population could find employment in the forest.

Another branch of the subject which is of interest from a geographical standpoint is the geographical distribution of forests over the face of the earth—why are there forests in one place and deserts and plains in another? What are the forces which cause the spread of forests and what are the barriers which prevent or restrict their growth? There are many aids to forest extension, such as winds, currents of water, animals, and man. There are many barriers which restrict their growth, such as cold, drought, unsuitable soil, strong winds, animals, and fire.

There is still another phase of the subject which is of importance to the geographical student. Every American should have some knowledge of our great forest reservations and national parks.

These reservations have been set aside for the preservation of the timber and natural curiosities and extraordinary scenery, and for the conservation of moisture, since in many western districts agriculture is impossible without water for irrigation. These reservations cover an area of almost 50,000,000 acres, a territory so large and varied that it is worthy some space in even primary geographies. There are 640 acres to the square mile—there would be then 78,125 square miles in these reservations. They cover an area much larger than the whole of New England states, three times as large as Greece, and almost five times as large as Switzerland.

The establishment of these reservations has apparently only just begun. A great park in the Appalachian Mountains and another at the head waters of the Mississippi in Minnesota will be in time established.

Already the State of New York owns a vast tract of land in the Adirondacks, and more is being purchased, for the preservation of the forests and game.

Under the circumstances, few can doubt that the subject is worthy a large place in our secondary schools and in the minds of our people.

J. GIFFORD

COLLEGE OF FORESTRY,
Cornell University

THE DIFFERENTIATION OF ZOÖLOGY FOR THE HIGH-SCHOOL AND COLLEGE CURRICULUM[1]

HIGHER education in the United States has resulted in the differentiation of three grades of institution: the high school, the college, and the university. Zoölogy is taught in all of these grades, and there is danger lest the proper sphere of each shall not be clearly defined, and so a loss of the students' energy result. It is the object of this paper to attempt to find tests by which to determine the respective sphere of college and high-school zoölogy.

The growth and development of a zoölogist presents three stages: first, an introductory stage in which observations are made over a wide horizon without the inner data of the subject being examined in much detail. 'Then a second stage of exact and careful acquisition of the existing knowledge of the subject. Then the professional and creative stage in which the student changes into the master, though always remaining a student, and joins the number of those who are engaged in the work of pushing the boundaries of knowledge out into new realms. There would be a great economy of his time if the zoölogist could be advanced successively on each of these stages in the high school, the college, and the university, and I believe that such a succession in the presentation of the subject would be better at the same time for the interests of a general education than any other.

The work of the first or introductory stage is to gain a first-hand and correct knowledge of representative members of the chief animal groups. They must, as many of them as the locality permits, be seen alive and in their native homes. Their activities, food, enemies, and relation to man should be learned, their outward forms and parts carefully observed, and all this

---

[1] Read before the College Section of the Minnesota Educational Association, December 29, 1900.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND Walter Mulford

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 62

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HYDROGRAPHY

OF THE

SOUTHERN APPALACHIAN MOUNTAIN REGION

PART I

By HENRY ALBERT PRESSEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

CONTENTS.

Page.

Letter of transmittal 9

Introduction 11

General features of region 11

  Mountains 11

    Physiography 11

    Geology 15

  Rivers 17

  Scenery 20

  Climate 22

  Precipitation 23

  Forests and lumbering 25

  Soil and vegetation 30

  Mineral resources 33

  Highways 33

Drainage basins 34

  Holston River 36

    Physical features 36

    Rainfall 40

    Agriculture 41

    Minerals 41

    Lumber 41

    Transportation 41

  South Fork of Holston River 42

    Physical features 42

      Area drained by the South Fork below junction with the Middle Fork 42

      Area drained by the South Fork above junction with the Middle Fork 45

      Area between the South and Middle forks 46

    Rainfall 47

    Forests 47

    Minerals 47

    Transportation 47

    Discharge measurements 47

    Water powers 48

  Tributaries of South Fork of Holston River below junction with the Middle Fork 53

    Discharge measurements 53

    Indian Creek 54

    Dry Creek 55

    Weaver Creek 55

    Hatcher Creek 55

    Morrills Creek 55

    Sinking Creek 56

    Thomas Creek 57

    Riddle and Jonah creeks 58

Drainage basins—Continued. Page.

Tributaries of South Fork of Holston River, etc.—Continued.

Fishdam Creek 58
Sharp Creek 58
Spring Creek 59
Jacobs Creek 60
Wolf Creek 60
Denton Valley Creek 61
Fifteenmile Creek 62
Tributaries of South Fork of Holston River above junction with the Middle Fork 62
Discharge measurements 62
Laurel Fork 63
Beaverdam Creek 65
Whitetop Creek 66
Rosenbaums Creek 67
Widner Creek 67
Rush Creek 67
Mill Creek 68
Grose Creek 68
St. Clair Creek 68
Wedstone Creek 68
Hogtrough Creek 68
Pomer Creek 69
Middle Fork of Holston River 69
Physical features 69
Discharge measurements 70
Water powers 70
Tributaries of Middle Fork of Holston River 73
Discharge measurements 73
Hogthief Creek 74
Cedar Creek 74
Halls Creek 75
Huttons Branch 75
Chilhowie Branch and Carlocks Creek 75
Walker Creek 75
Byars Creek 75
Hungry Mother Creek 76
Staleys Crêek 76
Bear Creek 77
Watauga River 77
Physical features 77
Area lying to the west of the Iron Mountains on the south side of the river 78
Area lying to the west of the Iron Mountains on the north side of the river 78
Area lying to the east of the Iron Mountains 79
Scenery 81
Rainfall 81
Springs 82
Timber 83
Minerals 83
Transportation 83
Discharge measurements 83
Water powers 84

Drainage basins—Continued.

Page.
Tributaries of Watauga River 85
  Discharge measurements 85
  Brush Creek 87
  Sinking Creek 87
  Buffalo Creek 87
  Gap Creek 88
  Doe River 88
    Little Doe River 88
    Laurel Fork 89
  Stony Creek 89
  Roan Creek 89
    Doe Creek 90
    Mill Creek 90
    Town Creek 91
  Elk Creek 91
  Beech Creek 92
  Beaverdam Creek 92
  Laurel Creek 93
  Cove Creek 93
  Dutch Creek 94
  Laurel Creek 94
  Boone Fork 94
Index, note concerning 95

ILLUSTRATIONS.

Page.
PLATE I. Map of Southern Appalachian region, showing mountain ranges and drainage ... 11
II. Map showing drainage basins of the Southern Appalachian Mountains and gaging stations maintained by Geological Survey ... 14
III. Escarpment of the Blue Ridge at Blowing Rock, N. C ... 16
IV. Typical forest-covered mountain side ... 20
V. Richland Valley from Junaleska Mountain, North Carolina ... 20
VI. Grandfather Mountain, North Carolina ... 22
VII. Grandfather Mountain, North Carolina, from Pixie; Grandmother Mountain in foreground ... 22
VIII. Skyuka Falls, North Carolina, a typical mountain waterfall ... 24
IX. View in the Sapphire country, North Carolina, showing smoothly rounded topography ... 24
X. Whiteside Mountain, North Carolina ... 24
XI. Poplar forest ... 26
XII. Pine forest ... 26
XIII. *A*, Wind-dwarfed balsam fir on Grandfather Mountain, North Carolina; *B*, Rhododendron thicket near Grandfather Mountain ... 26
XIV. *A* and *B*, Typical mountain homes ... 30
XV. Spring on Black Mountains, showing dense plant growth ... 30
XVI. *A*, View showing beginning of wash on mountain side; *B*, View of deforested hillside, showing effect of erosion ... 32
XVII. Water-washed gully in decomposed gneiss, McDowell County, N. C ... 32
XVIII. *A*, Sand and clay deposit in valley; *B*, Sand deposited upon farming land by river flood ... 34
XIX. *A*, Water-washed country road in Mitchell County, N. C.; *B*, Unimproved road in valley ... 34
XX. Mountain road near Sprucepine, N. C ... 36
XXI. Road in stream bed ... 36
XXII. Yonahlossee road, around the base of Grandfather Mountain, North Carolina ... 38
XXIII. Doe River Valley, Tennessee ... 88
XXIV. Elk Creek, North Carolina ... 90
XXV. Elk Falls on Elk Creek, North Carolina ... 90

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., December 18, 1901.

SIR: I have the honor to transmit herewith a manuscript prepared by Mr. H. A. Pressey, one of the hydrographers of this Survey, relating to the Southern Appalachian mountain region. This is the outcome of systematic measurements of the water supply from this area and of special investigations made in connection with a general inquiry as to the importance of the streams in the development of the country.

There has been a widespread movement for the acquisition by the Government of the forested lands within the Southern Appalachians and the setting aside of these as a reserve similar in character to the great forest reservations existing in the West. In this popular movement Prof. J. A. Holmes, State geologist of North Carolina, has been especially active. He has been cooperating with this Survey in all matters pertaining to the investigations in North Carolina, and has been the representative of the State in arranging for the disbursement of funds made available by the State for extending the systematic work carried on in that region. At his suggestion and with his active assistance the surveys and examinations described by Mr. Pressey have been made.

The importance of a full knowledge of this region is apparent when we consider the size and number of the streams issuing from this central mountain area. Water-power development, especially in the manufacture of cotton, is proceeding rapidly, and there is no portion of the country for which definite official data upon the water resources are more frequently required than for this area. I recommend, therefore, that the material prepared by Mr. Pressey be published in the series of Water-Supply and Irrigation Papers, as Nos. 62 and 63 of that series.

Yours respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

HYDROGRAPHY OF THE SOUTHERN APPALACHIAN MOUNTAIN REGION.

PART I.

By Henry A. Pressey.

INTRODUCTION.

The region herein described occupies portions of the States of Virginia, North Carolina, South Carolina, Tennessee, Georgia, and Alabama. It is elevated far above the surrounding country and stands out as a physiographic unit. Its rivers, topography, and resources are described in as much detail as the time available for field investigation permitted.

Special thanks are due to Mr. E. W. Myers, resident hydrographer for North Carolina and South Carolina, for his investigations and very complete reports on several of the drainage areas, the principal facts from which are embodied herein. Messrs. Cleveland Abbe, jr., L. V. Branch, N. C. Curtis, and Ernest Graves were also engaged upon the reconnaissance, and the success achieved was largely due to their assistance. The measurements of the streams to the south and west of the French Broad were under the charge of Prof. B. M. Hall, resident hydrographer for Georgia and Alabama, who was assisted by Max Hall, W. E. Hall, J. R. Hall, J. C. Conn, and H. G. Stokes. The photographs used for illustrations were taken by various members of the United States Geological Survey and of the United States Bureau of Forestry. Pls. IX and XI are from photographs by R. H. Scadin, Pls. XXXIX and XLII are by courtesy of Prof. J. A. Holmes.

GENERAL FEATURES OF REGION.

MOUNTAINS.

PHYSIOGRAPHY.

The great Appalachian mountain system stretches from Maine, in a general southwesterly direction for nearly 1,300 miles, through the States of Vermont, New York, Pennsylvania, Maryland, Virginia, North Carolina, South Carolina, and Tennessee, terminating in northern Alabama. In New York the range consists of high hills, the mountains gradually rising in elevation in Pennsylvania, where an average height of 2,000 feet above the sea, or 1,000 to 1,500 feet above the adjacent Cumberland Valley, is reached. At Potomac River, in the vicinity of Harpers Ferry, the elevation of the peaks is again reduced to about 800 feet. From the Potomac south the ranges are much higher and broader, spreading out into the great Blue Ridge, the Shenandoah, the Allegheny, and the Greenbriar mountains, ranges with broad, fertile valleys between, of which the Valley of Virginia, or Shenandoah Valley, has a national reputation for scenic beauty and fertility. Forty-five miles below the Potomac is Mount Marshall, 3,150 feet high, and a little farther south, near Luray, are Stoneyman and Hawks Bill, 4,031 and 4,063 feet high, respectively. These are the highest summits of the Blue Ridge north of North Carolina. The ranges extend in nearly parallel lines through the States of Virginia and West Virginia, and enter North Carolina and Tennessee near their common boundary, culminating in the Iron and the Great Smoky ranges, which with numerous cross chains form the great mountain region of the Southeastern States. In this mountain mass 288 peaks exceed a height of 5,000 feet, and 27 peaks have an elevation greater than Mount Washington (6,293 feet). From North Carolina and Tennessee the ranges extend more to the westward through Georgia and into Alabama, with outlying ranges in South Carolina, and are finally lost in hills forming the headwaters of the Gulf drainage. The general features of the southern and most massive portion of the Appalachians, with the drainage, are shown in Pl. I.

This great mountain system forms the backbone and watershed of the eastern part of the United States. The greatest masses and the highest peaks are in western North Carolina and eastern Tennessee, which region may be considered a high plateau, of which the Smoky Mountains form the western boundary of the highest portion and the Blue Ridge the eastern boundary. The latter ridge extends across the State of North Carolina in a general northeast-southwest direction until it reaches the southern border of the State, when it turns to the west and for a long distance (about 40 miles) forms a part of the boundary between North Carolina and South Carolina, passing at length into the State of Georgia and meeting again the Great Smoky Range. The area of the region included between these two ranges, which approaches to almost a point at its northern and southern extremes and at its widest portion has a width of 55 miles, is approximately 6,000 square miles.

The most striking characteristic of the Blue Ridge is the great difference in slope of its opposite sides. The rivers flowing to the west into the Tennessee and the Ohio head in the gaps upon the divide and for miles flow in broad, smoothly rounded, drift-filled valleys before entering the narrow, rock-cut gorges of their lower courses, while the rivers flowing to the east plunge downward in a series of cascades, falling several thousand feet in a distance of a few miles. The latter streams can hardly be said to have valleys, but simply V-shaped gorges, through which they tumble and foam until they reach the Piedmont Plain, which extends along the southeastern base of the Appalachian system. The surface of this plain has a general eastward slope from an altitude of about 1,000 feet at its western edge to 250 or 300 feet on the east, where it merges into the Coastal Plain.

The Smoky Mountains, on the western edge of the high plateau referred to, are extended to the north in the Bald and the Iron mountains and to the south in the Unaka Range. These mountains are much more massive and reach far greater elevations than the summits of the Blue Ridge. Many of their peaks attain heights of more than 6,000 feet. Unlike the Blue Ridge, their slopes are equally steep on both sides, their outlines are angular and rugged, and descents of 4,000 feet from the crest to the stream bed are not uncommon.

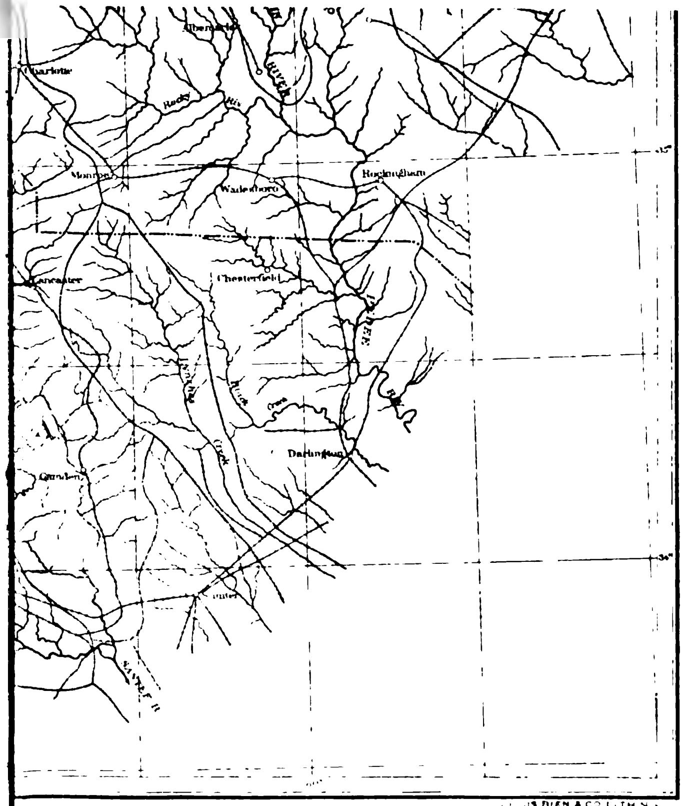
Several cross chains connect the Smoky and Blue Ridge ranges, cutting the plateau into a number of small basins, each nearly surrounded by mountains and having its own independent system of rivers and drainage, so that nowhere in this region do we find extended fertile valleys, as in Virginia and Tennessee, but instead in every direction high mountain ranges cut off the view and give it the appearance of a rocky and truly mountainous country.

The highest and most massive of the cross chains is the Black Mountains—named for their somber vegetation of balsam and other evergreens—which really consist of two chains having a united length of 40 miles and extending in a northwesterly direction from the Blue Ridge through the counties of Buncombe and Yancey and forming a connecting link between the Blue Ridge and the Smoky mountains. This range of mountains comprises 25 peaks, 18 of which are more than 6,000 feet in height. On their western slopes rise the eastern tributaries of the French Broad, the valley of which separates the Black Mountains from the Pisgah and the Newfound mountains, other of the cross chains, on the western slopes of which rise the eastern tributaries of Pigeon River. The western tributaries of the Pigeon flow from the Balsam Mountains, a range having an average elevation of 5,600 feet and comprising 23 summits with elevations exceeding 6,000 feet. This range extends from the South Carolina line to the Smoky Mountains. Still farther to the west are the Cowee Mountains, with a mean height of 4,800 feet. Rising at the southern end is Yellow Mountain, with an elevation of 5,133 feet. The last of the cross ranges to the west is the massive double chain of the Nantahala and the Valley River mountains, with a mean height of 5,000 feet. East of the Black Mountains are the Linville Mountains, through which Linville River has cut its stupendous chasm.

The Smoky and the Blue Ridge mountains, with their numerous cross chains, form the culmination of the Appalachian mountain system, and are the highest and most massive mountains in the United States east of the Rockies. Following is a list of the peaks which exceed in elevation 6,000 feet:

Highest peaks in Southern Appalachians.

	Feet.
Smoky Mountains:	
Mount Buckley	6,599
Clingmans Dome	6,660
Mount Love	6,443
Mount Collins	6,188
Mount Alexander	6,447
Mount Henry	6,373
Mount Guyot	6,636
Tricorne Knob	6,188
Ravens Knob	6,230
Thermometer Knob	6,157
Luftee Knob	6,232
Cataloochee Mountain	6,159
Roan High Knob	6,313
Roan High Bluff	6,287
Grassy Ridge (bald)	6,226
Mount Curtis	6,568
Mount Leconte	6,612
Master Knob	6,013
Oconee Mountain	6,135
Peck Peak	6,232
Mount Safford	6,535
Balsam Mountains:	
Enoe Plotts Balsam	6,090
Jones Balsam	6,224
Rockstand Knob	6,002
Brother Plott	6,246
Amos Plotts Balsam	6,278
Rocky Face	6,031
Double Spring Mountain	6,380
Richland Balsam	6,540
Chimney Peak	6,234
Spruce Ridge Top	6,076
Reinhardt Mountain	6,106
Devils Court-house	6,049
Sams Knob	6,130
Cold Mountain	6,000
Mount Hardy	6,102
Jones Knob	6,209
Mount Junaleska	6,223
Rocky Trail	6,488
Water Rock Knob	6,399
Black Mountain	6,275
Shining Rock	6,040
Rough Butt Bald	6,010
Cold Springs Knob	6,010



JULIUS BIEN & CO LITH N.Y.

Black Mountains:	Feet.
Blackstocks Knob (northwest chain)	6,386
Potato Top (northwest chain)	6,487
Black Dome (main chain)	6,502
Mount Gibbs (main chain)	6,608
Mount Hallback or Sugarloaf (main chain)	6,432
Mount Mitchell (main chain)	6,711
Balsam Cone (main chain)	6,697
Black Brother (main chain)	6,645
Cattail Peak (main chain)	6,609
Hairy Bear (main chain)	6,622
Deer Mountain (main chain)	6,220
Bowlems Pyramid or Celo (main chain)	6,351
Locust Mountain	6,088
Burnt or Long Mountain	6,238
Clingman Peak	6,611
Yeates Knob or Big Butt	6,001
Potato Knob	6,419
Patton Knob	6,079
Craggy Range:	
Big Craggy	6,106
Bull Head	6,072

The foregoing table shows a total of 64 peaks having elevations of 6,000 feet or higher. There are 288 peaks that exceed in height 5,000 feet, and the number that exceed 4,000 feet is much greater.

GEOLOGY.

For the following brief description of the geology of the region the writer is indebted to Mr. Arthur Keith, of the United States Geological Survey, who has made a careful study of the Southern Appalachians:

"The geologic formations which underlie this mountain district may be divided into four large groups. Each differs widely from the others in age, and has very distinct features of its own. These broad differences have expressed themselves in such major topographic features as the Appalachian Valley, the Appalachian Mountains, and the Piedmont Plateau. These differences are also largely responsible for the principal variations in the character of the surface in the mountain district itself.

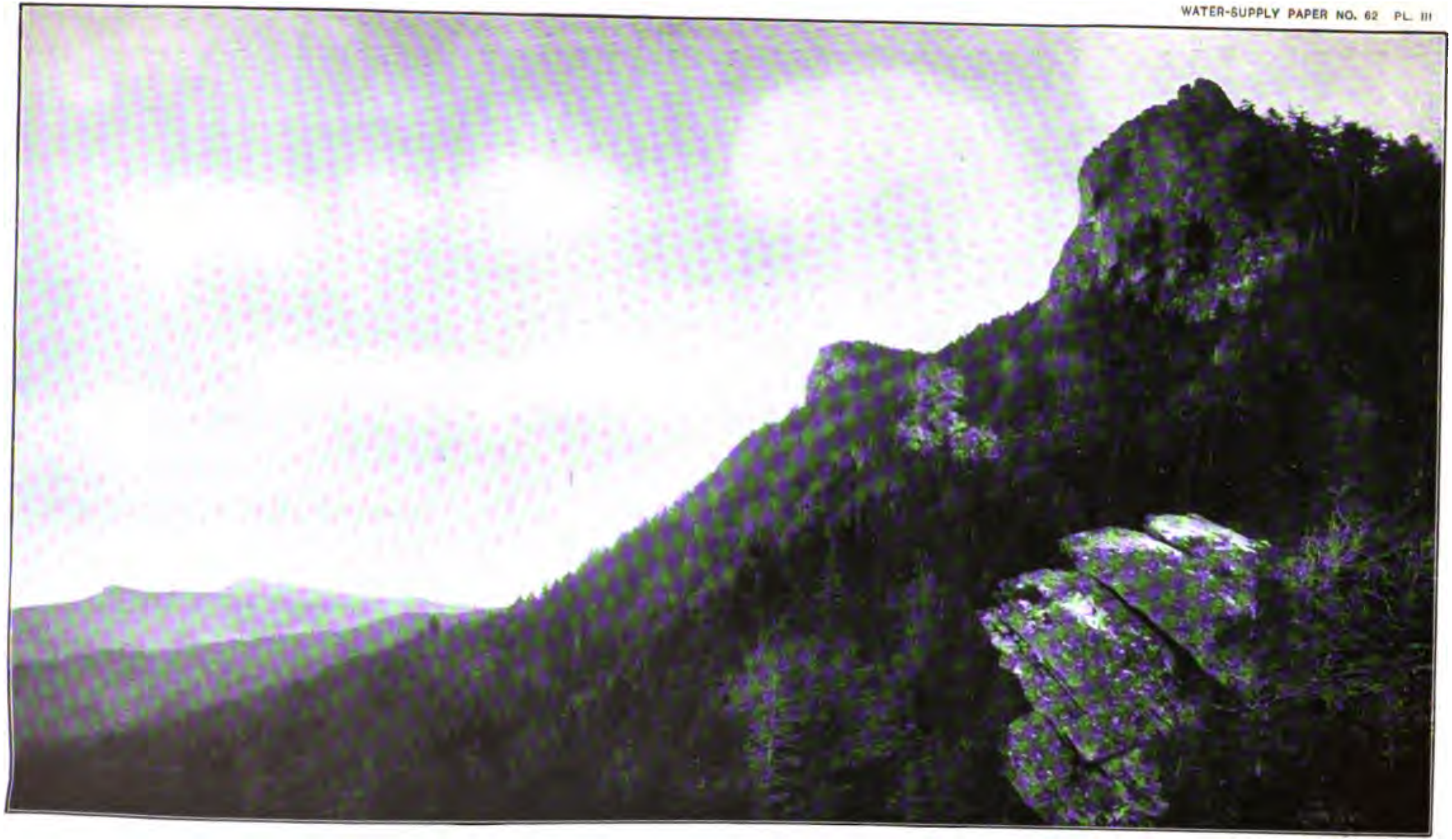
"The Appalachian Valley is underlain by a series of limestones, shales, and sandstones, mainly of Silurian and late Cambrian age, forming the youngest of the four groups in this region. Small outliers of these formations are included within the area of the mountains near the border of the Appalachian Valley.

"The second group occupies the northwestern border of the mountain district, chiefly northeast of French Broad River. It consists of a series of quartzites, conglomerates, and shales of Lower Cambrian age. A second large area of these rocks occupies the Blue Ridge and adjacent territory nearly in the center of this district.

"The third group is of Cambrian age. It occupies the northwest border of the mountain mass, corresponding in position to the previous group but developed southwest of French Broad River in the Smoky and the Unaka mountains. The group consists of conglomerates, graywackes, sandstones, schists, and slates, and is called the Ocoee group. This and the preceding two groups were composed of the waste from older rocks, which was deposited under water. The thickness of the strata is approximately the same in the Ocoee group and the formations of the Appalachian Valley. The Lower Cambrian quartzites and shales of the second group have only from one-fourth to one-third of the thickness of either of the preceding groups.

"The fourth group is much the largest of all, both in actual bulk and in area. It consists in the main of formations of the Archean, or oldest known age. The different rocks include several kinds of granite, diorite, mica- and hornblende-gneiss, and various schists. A large number of these were of igneous origin, but the original nature of many of the gneisses and schists is unknown. Formations also included in this group are the ancient volcanic rocks. These are developed most prominently in connection with the Cambrian quartzites in the northeastern part of the mountain district.

"Much of the surface of the Appalachian Mountains is exceedingly ancient. During the later geologic periods it has been subjected to the various natural agencies of destruction, and has been worn down according as the rocks presented at the surface were susceptible to these influences. The materials composing these formations are attacked in varying degrees by solution and by chemical processes connected with atmospheric and underground water. Certain minerals—for instance, carbonate of lime—are readily dissolved by natural waters, and the rock in wasting away leaves behind only the less soluble portions in the form of clay. To this capability is directly due the reduction of the great valley below the level of the mountain mass. Other minerals—for instance, feldspar—are in part dissolved and in part chemically altered and decomposed by natural waters, so that the coherence of the rock which contains them is largely destroyed. Two groups in this region have a large proportion of feldspar in their make-up, and their surfaces have been gradually lowered by its breaking down. These are the Ocoee group and the Archean group. A third mineral, quartz, is comparatively little changed by solution or chemical action near the surface. Formations made up in large part of this mineral retain their altitudes most persistently, and are usually the last to be reduced. This composition is most pronounced in the Lower Cambrian group, but is shared also by the Ocoee group and the Archean group. Although the thickness of the Lower Cambrian quartzites is so much less than that of the other groups, their resistance to solution has caused them to remain upheld in very high ridges and peaks. To this are due the cliffs of the Chilhowee, Camp



ESCARPMENT OF THE BLUE RIDGE AT BLOWING ROCK, N. C.

Creek, and Iron mountains, and the rugged crags of Grandfather. In the case of the Ocoee and Archean groups their immense thickness and the amount of quartz which they contain have maintained the greatest elevations presented in this region. Of this the mighty domes of the Smokies, the Balsams, and the Roan, and the lofty peaks of the Blacks are witnesses."

RIVERS.

The region is well watered. From it several of the largest rivers of the country receive their supply. The main divide of the river systems is the Blue Ridge. This chain, which enters the State of North Carolina in Alleghany County, extends southwest between Wilkes and Ashe counties and through Watauga County. At Grandfather Mountain, which is at the junction of Watauga, Mitchell, and Caldwell counties, the chain turns more to the south, following the boundaries between Mitchell and Caldwell counties and between McDowell, Yancey, and Buncombe counties, reaching the State line in Macon County. In this ridge and its spurs, cross ridges, and foothills many of the rivers of the Southeastern States have their origin. A view of an escarpment of the Blue Ridge at Blowing Rock, N. C., near Grandfather Mountain, is shown in Pl. III. The States of Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, and West Virginia are partially watered by rivers rising in mountains near the North Carolina and Tennessee State line. One of the principal upper tributaries of the Ohio (the Kanawha) and one of the largest feeders of the Mississippi (the Tennessee) head in the same mountains, and the region may justly be termed one of the chief watersheds of the United States. The drainage basins of the largest rivers are shown in Pl. II.

Flowing into the Atlantic are the Yadkin, Catawba, Broad, Saluda, and Chatooga; into the Gulf are the Chattahoochee and the Coosa. New River flows to the north and enters the Great Kanawha, whose waters finally reach the Mississippi through the Ohio River. Into the Mississippi flow the waters of the Tennessee and its large tributaries—the Holston, the Nolichucky, and the French Broad. From the western slopes of the Blue Ridge flow the headwaters of the great Tennessee river system. This drainage basin has an area of about 1,500 square miles and a length of 300 miles in North Carolina, and a fall of about 1,000 feet between its source and the North Carolina and Tennessee State line. The Cheoah, the Nantahala, the Oconalufty, and the Tuckasegee, all large streams with a width of from 50 to 100 yards, join their waters to the Tennessee, and after receiving them the latter river flows through the Great Smoky Mountains in a narrow and rocky gorge. The Hiwassee joins it in Tennessee.

All of the large streams that flow to the west have the same general characteristics, i. e., heavy, precipitous falls in the first portion of their courses, then long even flows, with but little fall, across the broad plateaus, finally cutting through the mountain ranges on the border line of North Carolina and Tennessee, where they have rapid and precipitous falls, in some cases more than 1,000 feet in a few miles.

After leaving the State of North Carolina the Tennessee flows in a northwesterly direction for about 300 miles, through the State of Tennessee, being joined by the Holston and the Nolichucky, tributaries which carry as much water as the parent stream. The Holston receives its southern branches from this same mountain region. The Watauga, one of the chief tributaries of the Holston, rises in the center of the mountain district around Grandfather Mountain, and flows in a northwesterly direction through Watauga County, with the high, steep slopes of the mountain sides on either hand, and with frequent falls of a few feet over its rocky bed. After flowing through the Iron Mountains in a rocky gorge and entering Tennessee the Watauga is joined by Roan and Elk creeks, which have drainage areas with the same characteristics as its own. After the junction of these three streams the river flows through Carter and Washington counties, receiving tributaries on either side, the chief of which are Doe River, Buffalo Creek, and Stony Creek. About 20 miles southwest of Bristol the Watauga joins the South Fork of the Holston, and farther down, near Kingsport, the two forks of the Holston unite, forming one of the chief rivers of the State of Tennessee. Near Knoxville the Holston is joined by Nolichucky River, a stream but little smaller than itself, which derives its headwaters a few miles south of the source of the Watauga.

The Nolichucky is formed by the junction of the North Toe, the South Toe, and Caney River, all of which rise in the high mountains of Mitchell and Yancey counties, on the western border of North Carolina. The headwaters of the North Toe are separated from those of Elk Creek, of the Watauga drainage, by a narrow ridge. The North Toe flows to the southwest until its junction with the South Toe, which rises in the Black Mountains, after which it flows in a westerly direction and is joined by Caney River, which also rises in the Black Mountains but flows through a comparatively flat and open valley, draining a large part of Yancey County. After the junction with Caney River the stream is known as the Nolichucky, and flows to the west for 200 miles through the State of Tennessee, receiving numerous tributaries, the chief of which are Lick Creek and French Broad and Pigeon rivers.

The French Broad rises in the Blue Ridge, at the State line between North Carolina and South Carolina, flows in a northwesterly direction, at first with considerable fall, then enters the broad plateau, and with sluggish, even flow continues its course westward until it breaks through the Bald Mountains. Numerous tributaries are received on either side, all of which in their lower courses have the characteristics of rivers of the plains. The fall of the French Broad from Brevard to Asheville, a distance of 50 miles, is 2.7 feet per mile.

On the north side of Grandfather Mountain are the headwaters of the South Fork of New River. This is the only stream in this region that flows northward. It drains about half of Watauga and Ashe counties, and flows through narrow valleys with steep mountain slopes on either side. After passing into Virginia it is joined by the North Fork of New River, and flows for 100 miles through that State, finally entering West Virginia, where it empties into the Great Kanawha, adding its waters to the Ohio.

From the southern slopes of Grandfather Mountain and the ridge between the towns of Grandfather and Blowing Rock flow the headwaters of the Yadkin. For the first few miles the stream is small and the fall very great, being through a rough and wooded country; but soon the river reaches the vast plateau known as the Piedmont Plain, and its valley opens out into a broad and fertile area, with numerous branches on either side, those from the south, which rise in the Brushy Mountains, being small, while those from the north, which rise in the Blue Ridge, are streams with large flow and considerable fall. The many tributaries add large volumes of water to the Yadkin, and as it flows to the east its discharge increases rapidly, until by the time the South Carolina boundary line is reached it has become one of the largest rivers of the Southeastern States. It flows for 130 miles through the State of South Carolina under the name of Pedee River.

The many springs on the southern slope of Grandfather Mountain join to form John River and Mulberry and Wilson creeks, which unite about 20 miles to the south and finally add their waters to Catawba River. The Catawba rises in the Black Mountains and flows east, descending from the high mountain sides to the level of the Piedmont Plain in frequent leaps of from 5 to 10 feet, and in one or two cases with vertical falls of 100 feet. From Oldfort, in McDowell County, it flows through the heart of the Piedmont Plain, receiving large tributaries from the north, notably North Fork, Linville River, Upper Creek, John River, and Lower Creek, all of which rise on the eastern slopes of the Blue Ridge, two of the chief tributaries, Linville and John, receiving their headwaters from the springs on the slopes of Grandfather Mountain. The river flows to the east, entering Alexander County, where it turns to the south and crosses the South Carolina boundary, after which it is known as the Wateree.

There are two rivers in this region which differ somewhat in their general characteristics from the streams described, viz, the Broad and the Saluda. Broad River is formed by the junction of the main Broad, the Green, the First Broad, and the Second Broad, and receives its headwaters from the slopes of South Mountain and the Blue Ridge. The tributaries, however, soon reach the flat, open plain, and uniting near the State line enter South Carolina near the western border of York County. Farther to the southwest Saluda River receives the run-off from the Blue Ridge and flows for almost its entire length through South Carolina. Tugaloo River, which flows into the Savannah; Oconee River, one of the chief streams of Georgia and a tributary of the Altamaha; and the Chattahoochee, which waters in part the States of Georgia, Alabama, and Florida, also rise in the Blue Ridge.

SCENERY.

The scenery of the Southern Appalachian region is the grandest in the Eastern States. While in height the mountains can hardly be compared with the Rockies or the Alps, they far outstrip in height, massiveness, and extent the mountains of the Northeastern States. As one ascends Roan Mountain or Grandfather Mountain or passes through Hickory Nut Gap he is strongly reminded of the scenery of Switzerland, and might well imagine that he was on the Rigi or the Pilatus.

The mountains and valleys are covered with a luxuriant growth of forest trees, making one continuous bank of green from the bases to the summits of the highest peaks. (See Pl. IV.) With tireless energy the rivers have cut their ways through the massive ranges and formed stupendous gorges with bare, rocky walls almost vertical and hundreds of feet in height. These gorges, which confine the wandering streams, present views of rare grandeur and wonderful beauty. The charms of the Linville (see Pl. XXXVIII, Part II), the Cranberry, and the Watauga can not fail to arouse the wonder and admiration of all who visit them. Among the mountains and adjoining elevated plateaus there are a number of places where people seek rest and recreation during the hot months of the year. The visitors, however, are largely from the Southern States, and after spending a summer in these mountains the writer can but marvel that they have been so long overlooked by the people of the Eastern States as an ideal place to enjoy beautiful scenery and exhilarating mountain air. It can be accounted for only by the fact that so little has been known regarding the region, and that it is, unfortunately, rather difficult of access, there being few railroads except those used for lumbering, and the highways being execrable. These drawbacks, however, are rapidly disappearing, and the region would well repay a visit from the tourist or the seeker for health.

In general the mountain views are made up of a billowy succession of ridges (shown in Pl. V), the deep green of the mountains melting into the blue of the sky in the distance, while nearer at hand more subdued shades of green prevail, which in the valleys below merge into the soft, ripe yellows of the grain fields, with here and there a bare cliff or an area of red soil which stands out in sharp contrast. From the Unakas and to the north and west, where lies the beautiful Valley of East Tennessee, the views are of a different character. There the inequalities of surface are almost lost, and for miles the eye rests on a great plain dotted with light-colored cultivated areas and with green forest masses. Among the Unakas many balds occur, of which

TYPICAL FOREST-COVERED MOUNTAIN SIDE.

RICHLAND VALLEY FROM JUNALESKA MOUNTAIN, NORTH CAROLINA.

Whitetop is one of the most conspicuous and those of the Roan the most extensive and beautiful, consisting, as they do, of three or four peaks extending along the top of the mountain in a chain about 6 miles long. Dr. Mitchell many years ago said of Roan Mountain: "It is the most beautiful, and will best repay the labor of ascending it, of all our high mountains. With the exception of a body of rocks looking like the ruins of an old castle, near its southwestern extremity, the top of the Roan may be described as a vast meadow without a tree to obstruct the prospect, where a person may gallop his horse for a mile or two, with Carolina at his feet on one side, and Tennessee at the other, and a green ocean of mountains rise in tremendous billows immediately around him." Some of the highest peaks, however, are not bald, but are covered with a dark and dense growth of balsam and other evergreens. It is from a somber vegetation of this kind that the Black Mountains derive their name.

From Mount Mitchell a view into six States can be had. Although that mountain is the highest peak east of the Rockies, the views from it are not so fine nor so extensive as can be obtained from other mountains of less elevation, for the reason that it is surrounded by peaks with altitudes little less than its own, while Roan Mountain and Grandfather Mountain tower far above their surroundings, and from them magnificent views can be obtained in all directions.

Grandfather Mountain (shown in Pls. VI and VII) is probably the most massive of the Southern Appalachians, and is the culmination of the Blue Ridge. The scenery from it is unsurpassed. For many miles range after range of mountains spread out like the waves of the ocean, with opalescent clouds hanging down in the valleys below. In spring and summer there is the glint of the sunshine on the moist green of the leaves. In autumn the somber green of the balsam and spruce crowning the summits rises above the scarlet and golden glories of the foliage of the hard-wood trees, while in winter the great peaks lie cold and white, bare and forbidding. At every turn some new and beautiful thing is offered. Below the peaks myriad little brawling crystal streams dash in fleecy white over the ledges and around the bowlders that obstruct their courses (see Pl. VIII), or loiter in still pools where the rainbow trout lurk, while still lower are the green valleys hemmed in by the great mountains. On the slopes of Grandfather Mountain, from near the summit to the base, rise innumerable springs of pure, cold water, which uniting form rivulets that flow over rocky precipices and are finally joined into one of the several rivers which flow from its base. The mountain is covered with a heavy forest growth which has not yet known the woodman's ax. Nearly the whole of it, as well as its neighbor, Grandmother Mountain, is owned by the Linville Improvement Company, which controls 16,000 acres of the region, largely covered with forests, and, fortunately, lumbering is not their design. The company has laid out a town site in the valley of Linville River, at the foot of Grandfather Mountain, and intends to sell small tracts to those who desire summer homes in the mountain region. In order that the springs which give rise to the streams on Grandfather Mountain may not be disturbed, 1,400 acres have been set aside as a public park, under five commissioners, one of whom is the State geologist and another the commissioner of agriculture of North Carolina.

The general contour of the mountains in the Southern Appalachian region is gentle, with smoothly rounded outlines (see Pl. IX), although occasionally sharp peaks are seen and here and there immense precipices are brought into view, especially in the southern portion of the region, as at Whiteside Mountain, one side of which presents a sheer face of naked rock 1,800 feet in height. (See Pl. X.)

CLIMATE.

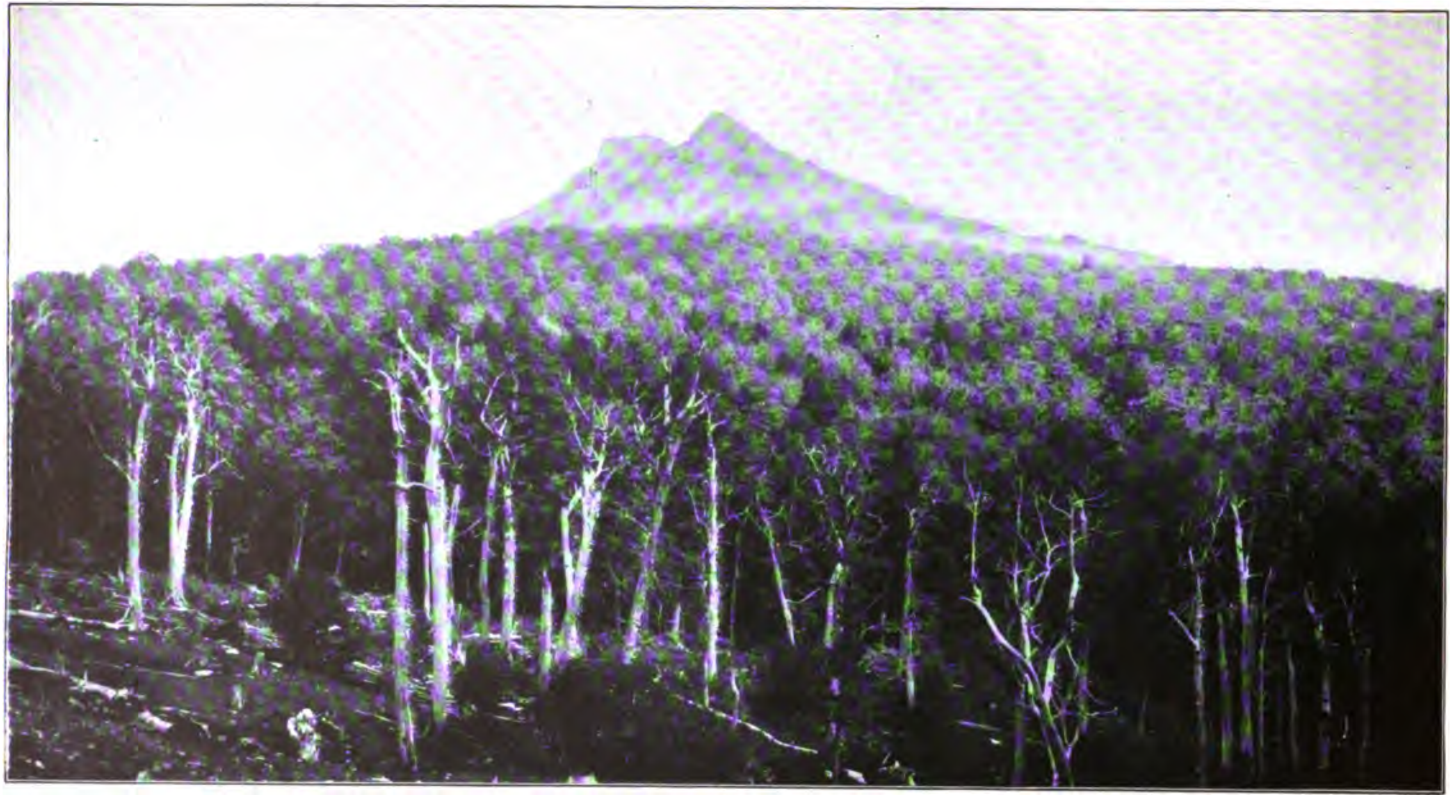
As has been stated, the Blue Ridge may be considered the great water divide. The mountain region lies to the north and west, while on the east is the Piedmont Plain. The effect of the increased altitude upon the climate is apparent. The high plateau may be said to have cooler summers and more severe winters than the lower lands adjacent, the air is drier and more salubrious, the summer months are remarkably pleasant, the temperature varying somewhat with the altitude, but never too cold for comfort on even the highest mountain peaks. By choosing the proper locality one can obtain an average temperature corresponding to that of northern New England or to the warmer temperatures of the South Atlantic States. The mean annual temperature varies from nearly 60° F. at Salisbury, east of the mountains, to 49° F. at Linville, the latter being about the mean annual temperature of Boston and Chicago. On the mountain slopes the mean annual temperature is still lower. The seasonal temperatures of the mountain region are approximately as follows: Spring, 56°; summer, 73°; autumn, 57°; and winter, 40°. The following table gives the average monthly temperature, the mean annual temperature, and the seasonal temperatures as observed at the Weather Bureau stations in the mountain region:

Temperature observations in Southern Appalachian Mountains during 1900.

Station.	Average monthly temperature.												Mean annual temperature.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	Deg.	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*
Biltmore	36.1	34.3	44.9	56.2	63.9	70.8	74.6	74.8	69.9	59.8	47.5	39.4	56.0
Charlotte	41.4	39.5	48.1	59.6	69.0	74.8	79.4	81.9	76.4	65.2	52.0	42.6	61.8
Henrietta	41.0	39.5	50.0	60.0	68.3	74.6	79.9	81.5	76.0	64.8	52.4	43.1	60.9
Hendersonville	36.6	34.6	45.1	54.4	62.4	70.2	73.4	75.4	70.4	62.6	50.0	40.5	56.3
Highlands	32.8	30.6	38.4	51.0	58.4	64.1	67.5	68.1	[a]63.6	56.2	45.3	35.8	51.0
Horse Cove	38.4	35.5	43.6	56.0	62.8	66.6	71.6	74.4	69.4	60.4	49.6	40.6	55.7
Linville	30.3	29.0	36.8	48.0	55.6	64.5	67.2	67.6	63.1	54.3	43.6	34.0	49.5
Morganton	......	......	......	......	......	73.8	79.0	80.0	74.0	62.1	50.0	41.4	......
Mount Airy	37.0	35.6	42.6	55.8	62.4	70.0	76.6	77.6	71.7	61.9	48.7	38.8	56.6
Marion	38.8	36.2	46.8	57.8	66.6	72.8	78.2	80.1	75.2	63.3	51.2	41.5	59.0
Marshall	33.8	34.6	43.2	54.6	64.2	72.0	75.8	76.5	[b]69.6	61.2	......	......	......
Waynesville	35.2	36.1	43.6	52.6	61.0	68.5	71.8	71.4	67.2	58.4	44.0	37.5	53.9

[a] Record for three days missing.

[b] Record for six days missing.



GRANDFATHER MOUNTAIN, NORTH CAROLINA.

CENTER, GRANDFATHER MOUNTAIN, NORTH CAROLINA (HIGH PEAK IN BACKGROUND), FROM PIXIE.

Temperature observations in Southern Appalachian Mountains, etc.—Continued.

Station.	Seasonal temperatures.				Latitude.	Longitude.	Elevation.	Length of record.
	Spring.	Summer.	Autumn.	Winter.				
	Deg.	*Deg.*	*Deg.*	*Deg.*	° ′	° ′	*Feet.*	*Years.*
Biltmore	55.0	73.4	59.0	36.6				2
Charlotte	58.9	78.7	64.5	41.2	35 13	80 51	808	22
Henrietta	59.4	78.7	64.4	41.2				
Hendersonville	54.0	73.0	61.0	37.2				1
Highlands	49.3	66.6	55.9	33.1	35 5	83 25	3,817	15
Horse Cove	54.1	70.9	59.8	38.2	35 0	83 6	2,800	6
Linville	46.8	66.4	53.7	31.1	36 5	81 51	3,800	4
Morganton		77.6	62.3		35 45	81 44	1,135	9
Mount Airy	53.6	74.7	60.8	37.1	36 30	80 40	1,048	10
Marion	57.1	77.0	63.2	38.8	35 30	82 5	1,425	5
Marshall	54.0	74.8						
Waynesville	52.4	70.6	56.5	36.3	35 29	82 58	2,756	4

Highlands, the highest station, is 3,817 feet in elevation, while several of the mountain ranges and peaks reach altitudes of from 5,000 to 6,000 feet, and their temperatures are lower than those given in the table. The following table gives the temperature extremes at a number of observation stations:

Temperature extremes in Southern Appalachian region.

Station.	Elevations.	Length of record.	Highest monthly mean.		Lowest monthly mean.		Highest observed.		Lowest observed.	
			Temperature.	Date.	Temperature.	Date.	Temperature.	Date.	Temperature.	Date.
	Feet.	*Yrs*	*Deg.*		*Deg.*		*Deg.*		*Deg.*	
Asheville	2,250	23	74.8	July, 1879	27.2	Jan., 1893	95	Sept. 15, 1897	[a]— 9	Jan. 16, 1893 Feb. 8, 1895
Chapel Hill	500	41	82.2	July, 1893	28.4	Jan., 1857	105	Aug. 10, 1892	— 1	Jan. 16, 1893
Greensboro	843	15	82.6	do	32.3	Dec., 1876	101	Aug. 10, 1896	6	Jan. 28, 1897
Highlands	3,817	15	70.9	July, 1878	24.4	Jan., 1893	86	June —, 1891	—17	Feb. 8, 1895
Horse Cove	2,800	6	74.4	July, 1893	28.5	do	93	Sept. 15, 1897	—13	Do.
Lenoir	1,186	26	77.7	July, 1877	27.3	do	95	July 18, 1887	—16	Dec. —, 1880
Morganton	1,135	10	80.0	July, 1868	26.4	do	100	Sept. 16, 1897	— 1	Jan. 16, 1893
Mount Airy	1,048	10	77.1	July, 1872	26.2	do	98	Sept. 28, 1891	—15	Do.
Mount Pleasant	650	12	79.1	Aug., 1896	29.9	do	98	June 29, 1889	— 4	Jan. 21, 1893
Murphy	1,614	12	76.9	July, 1878	28.5	Dec., 1876				
Salisbury	760	13	82.0	July, 1893	33.0	Jan., 1893	102	Aug. 10, 1896	5	Feb. 21, 1896

[a] Minus sign indicates temperature below zero.

PRECIPITATION.

The annual rainfall is copious, larger than anywhere else in the United States except on the northwestern coast, in Oregon and Washington. As might be supposed, it varies considerably in different parts of the high regions. The warm, moist winds from the east and south are deflected upward by the Blue Ridge, causing a cooling and consequent precipitation. In this way the yearly rainfall is greatly increased on the slopes of those mountains. At Highlands, in Macon County, the annual normal precipitation is about 72 inches and at Horse Cove about 73 inches. West of the Blue Ridge the annual rainfall is much less in the valley bottoms between the mountain ranges. For instance, a long record at Asheville gives a normal rainfall of about 42 inches, the smallest of any record of the mountain region. The normal at Waynesville, in Haywood County, is 46 inches. The average precipitation of the whole region may be considered to be approximately 53 inches. The following table gives the monthly, annual, and seasonal precipitation for 1900:

Precipitation in Southern Appalachian region during 1900.

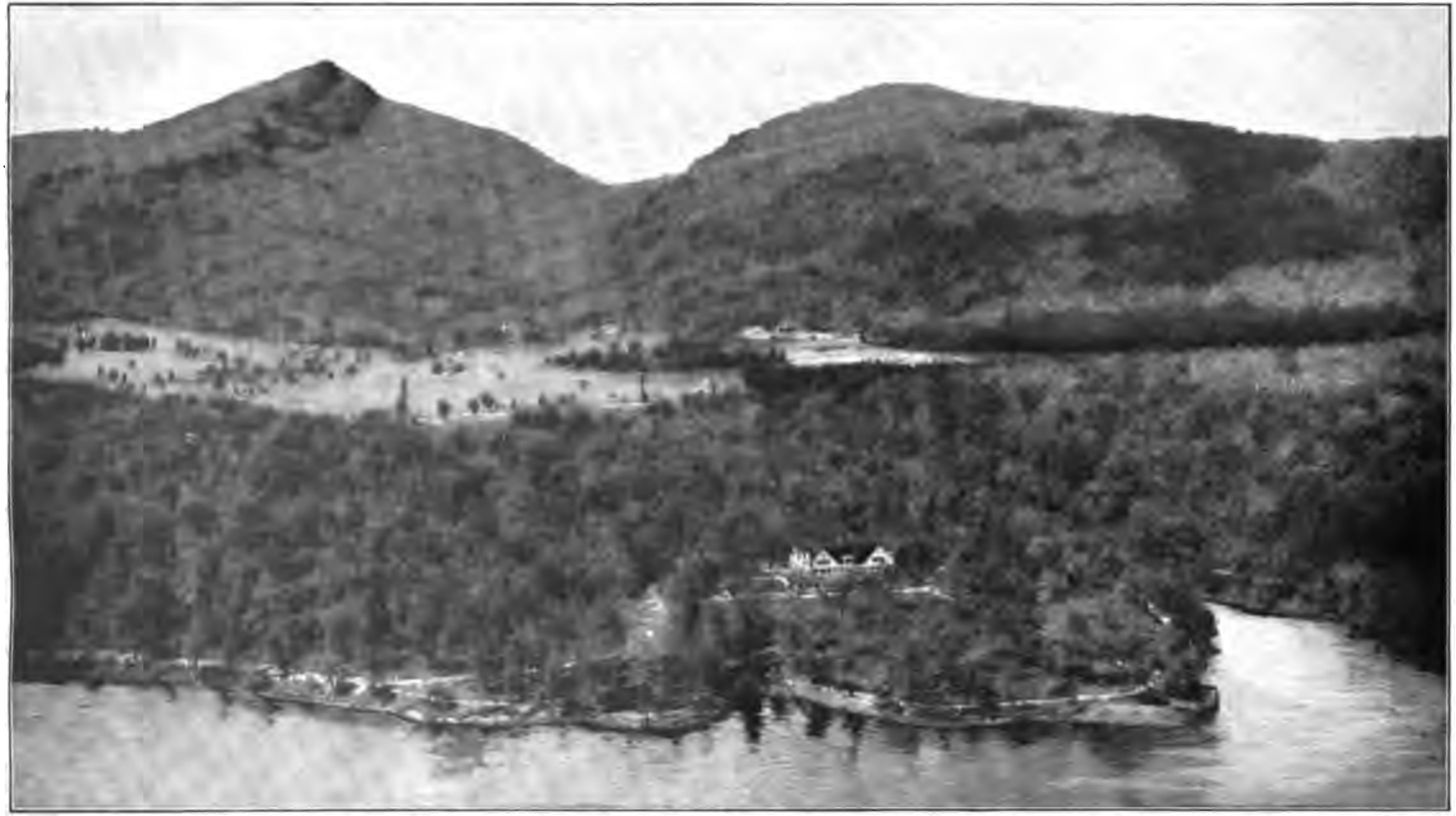
Station.	Monthly precipitation.												Mean annual.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Abshers	3.35	7.50	4.92	4.89	2.98	9.28	7.43	4.14	5.46	8.73	5.15	3.35	67.13
Asheville	2.26	4.67	5.53	4.18	0.99	8.11	1.99	2.54	3.39	2.92	4.62	3.46	44.66
Biltmore	2.41	6.90	2.87	3.31	1.37	7.91	2.10	0.52	2.51	3.67	3.34	3.80	40.71
Bryson	2.85	7.72	7.33	4.67	1.21	6.31	2.88	4.48	3.02	2.87	4.80	4.76	52.90
Charlotte	2.15	5.25	5.28	5.32	2.11	7.31	3.55	3.05	0.73	3.41	3.85	4.83	46.34
Cherryville	3.31	7.01	5.65	7.55	3.34	6.39	2.25	2.61	2.01	2.29	4.04	4.80	51.25
Flatrock		13.24	5.06							8.17	3.87	3.90	
Hendersonville	3.94	10.10	5.76	8.06	3.83	8.79	5.75	1.53	3.80	4.10	3.47	4.98	64.11
Henrietta	3.09	10.69	5.29	6.77	2.92	6.99	2.79	1.45	1.05	4.15	5.27	5.10	55.56
Highlands	5.82	13.84	7.10	10.20	1.67	19.29	8.04	1.95	4.99	6.00	5.03	7.53	91.46
Horse Cove	4.28	12.98	7.10	8.83	2.28	19.92	9.43	3.36	6.74	8.63	5.94	6.67	96.16
Linville	2.63	5.34	7.60	5.51	2.17	7.07	3.99	3.70	4.42	13.40	4.47	3.95	64.25
Maria	2.13	5.17	4.06										
Marion	3.59	9.22	6.65	9.70	1.96	10.50	3.52	2.70	3.48	9.69	4.04	4.74	69.79
Marshall	1.26	4.07	3.69	2.62	1.46	8.33	1.49	2.69	3.63	3.51	2.25	3.09	38.09
Mount Airy	2.35	4.00	[a]3.50	[a]3.67	1.02	8.56	3.52	2.50	4.12	4.04	3.10	3.38	43.76
Mount Pleasant	2.11	6.68	3.07	4.34	2.53	4.87							
Morganton						5.97	2.65	1.15	2.10	3.20	2.26	4.40	
Mocksville	3.40	4.38	6.18	4.68	3.13		2.88	2.07	2.08	3.04	3.31	3.32	
Murphy	3.55	6.45	7.07	4.88	2.19	8.87	4.04	2.78	3.19	5.19	5.22	5.45	58.83
Salisbury	3.22	4.52	5.02	4.98	4.12	4.81	3.52	1.79	1.60	1.90	2.10	6.35	43.93
Settle	2.82	5.34	3.30	4.30	2.40	5.57	2.43	3.95	3.56	2.99	3.08	4.51	44.25
Waynesville	2.38	6.97	6.00	6.41	1.01	7.64	3.55	2.25	2.49	2.12	3.57	4.08	48.47

Station.	Seasonal precipitation.				Latitude.	Longitude.	Elevation.	Length of record.
	Spring.	Summer.	Autumn.	Winter.				
	In.	*In.*	*In.*	*In.*	° ′	° ′	*Feet.*	*Years.*
Abshers	12.74	20.85	19.34	14.20				
Asheville	10.70	12.64	10.93	10.39	35 37	82 30	2,250	22
Biltmore	7.55	10.53	9.52	13.11			2,150	2
Bryson	13.21	13.67	10.69	15.33	35 27	83 23	2,000	10
Charlotte	12.71	13.91	7.99	11.73	35 13	80 51	808	23
Cherryville	16.54	11.25	8.34	15.12				
Flatrock					35 15	82 25	2,214	6
Hendersonville	17.65	16.07	11.37	19.02			2,167	1
Henrietta	14.98	11.23	10.47	18.88				
Highlands	18.97	29.28	16.02	27.19	35 5	83 25	3,817	15
Horse Cove	18.21	32.71	21.31	23.93	35 0	83 6	2,800	6
Linville	15.28	14.76	22.29	11.92	36 5	81 51	3,800	4
Maria								
Marion	18.31	16.72	17.21	17.55			1,425	5
Marshall	7.77	12.51	9.39	8.42				
Mount Airy	8.19	14.58	11.26	9.73	36 30	80 40	1,048	10
Mount Pleasant	9.94				35 28	80 28	650	12
Morganton		9.77	7.56				1,135	9
Mocksville	13.99		8.43	11.10	35 51	80 34	651	4
Murphy	14.00	15.69	13.60	15.45	35 8	84 0	1,614	20
Salisbury	14.12	10.12	5.60	14.09	35 4	80 29	760	13
Settle	10.00	11.95	9.63	12.67				2
Waynesville	13.42	13.44	8.18	13.43	35 29	82 58	2,756	4

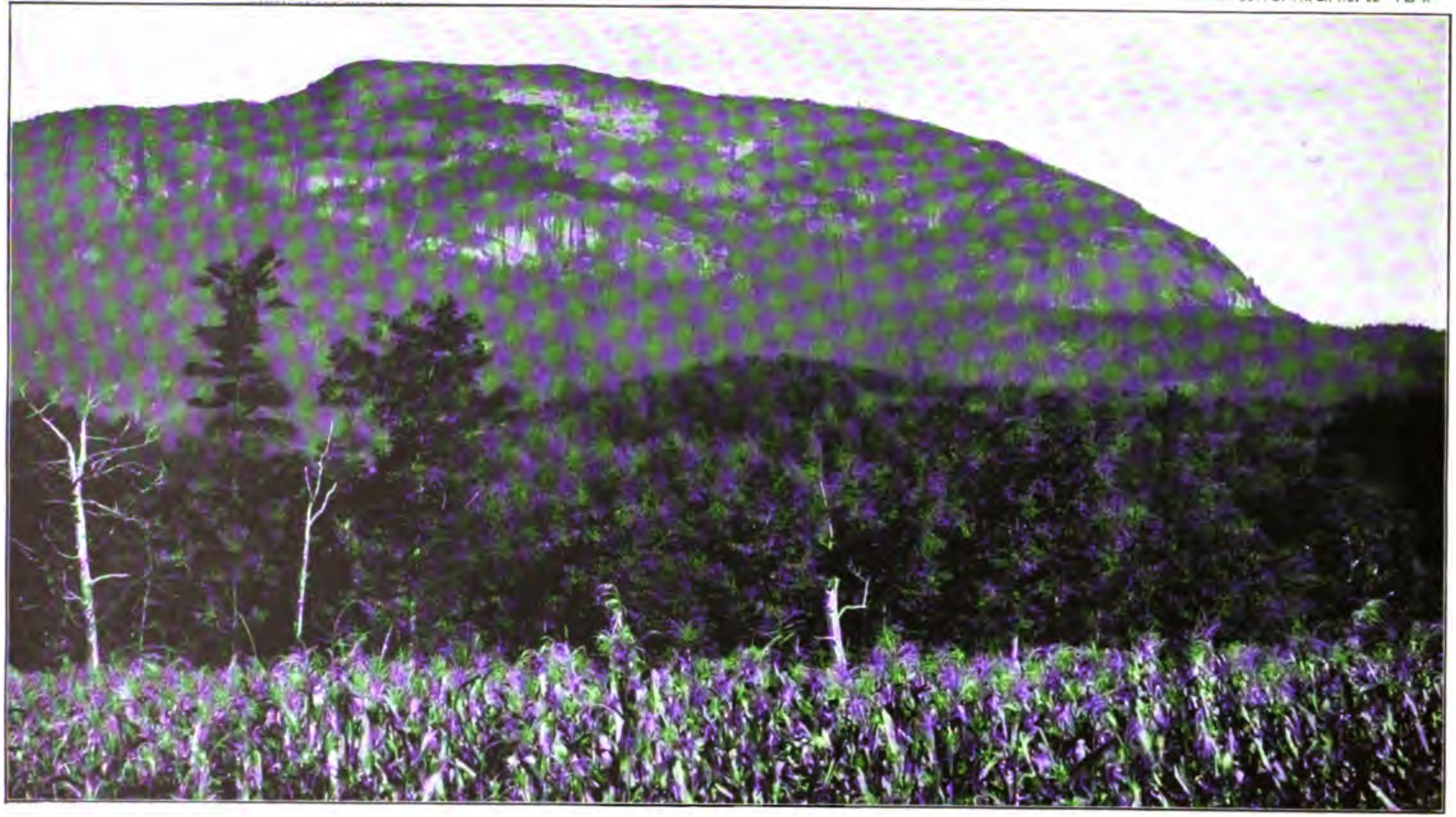
[a] Partly estimated.

Heavy rains occur at short intervals, which with the steep slopes cause rapid increase in the flow of the streams for a day or a few

SKYUKA FALLS, NORTH CAROLINA, A TYPICAL MOUNTAIN WATERFALL.



VIEW IN THE SAPPHIRE COUNTRY, NORTH CAROLINA, SHOWING SMOOTHLY-ROUNDED TOPOGRAPHY.



WHITESIDE MOUNTAIN, NORTH CAROLINA.

hours, when the rivers as rapidly fall to their normal stage. Floods are frequently caused by the heavy rains. It is exceedingly difficult, however, to obtain measurements of the extreme high waters, for unless one is near the station at the time the water rises the river falls before he can reach there. A rainfall of 7.39 inches was recorded at Salisbury on June 10, 1883, and 6.01 inches at Highlands on February 8 and 9, 1891.

There is considerable snowfall during the winter months of the year, the average annual snowfall at a few stations being as follows: Asheville, 16 inches; Highlands, 22 inches; Lenoir, 11 inches; and Mount Airy, 12 inches.

The following table gives the greatest and least monthly precipitation:

Table showing greatest and least monthly precipitation in Southern Appalachian region.

Station.	Elevation.	Length of record.	Greatest monthly precipitation.		Least monthly precipitation.		Highest monthly average.	Lowest monthly average.
			Amount.	Date.	Amount.	Date.		
	Feet.	*Years.*	*Inches.*		*Inches.*		*Per cent.*	*Per cent.*
Asheville	2,250	23	[a]11.40	July, 1874	0.21	Oct., 1895	143	74
Charlotte	808	22	11.13	Mar., 1891	0.23	Nov., 1890	126	74
Highlands	3,817	15	20.20	Feb., 1891	0.25	May, 1883	135	79
Horse Cove	2,800	6	17.02	June, 1892	0.62	Oct., 1892	136	38
Lenoir	1,186	26	11.50	May, 1873	0.00	Nov., 1890	133	78
Morganton	1,135	10	11.20	Apr., 1878	0.20	Oct., 1892	129	67
Mount Airy	1,048	10	10.38	July, 1889	0.17	Nov., 1890	147	60
Mount Pleasant	650	12	10.27	Aug., 1887	0.28	Oct., 1892	142	66
Salisbury	760	13	16.14	do	0.13	Nov., 1890	128	67

FORESTS AND LUMBERING.[b]

Nearly the whole of these mountains was once covered with a magnificent growth of timber, which owing to its inaccessibility was long spared the woodman's ax. Now, however, since the forests of the North and the West have been denuded, the lumbering element has turned its attention to the Southern Appalachians, and the vast forests there are rapidly disappearing. Railroads have penetrated the mountains, and mills large and small have been located in the forested areas. One great railroad traverses the heart of the region, with a branch from Asheville through Macon and Cherokee counties. Lines have also been constructed up Doe and Nolichuky rivers, and a number of other lines have been surveyed, some of which will probably be built within a few years. Wherever a railroad is constructed the neighboring timber soon disappears, in consequence of the cheaper transportation. Most of the large mills are steam sawmills, and they are moved deeper into the forests as the supply of timber in their immediate vicinity is exhausted, the railroads being extended to them. Near the rivers the logs are splashed down the streams to the timber pens of the mills below, thus saving the cost of railroad transportation or long hauls over rough and steep roads. Splash dams are constructed which hold back the water in dry seasons and float the logs over the rocky beds of the streams.

---

[a] There is record of a greater amount than this, but it is not considered quite trustworthy.

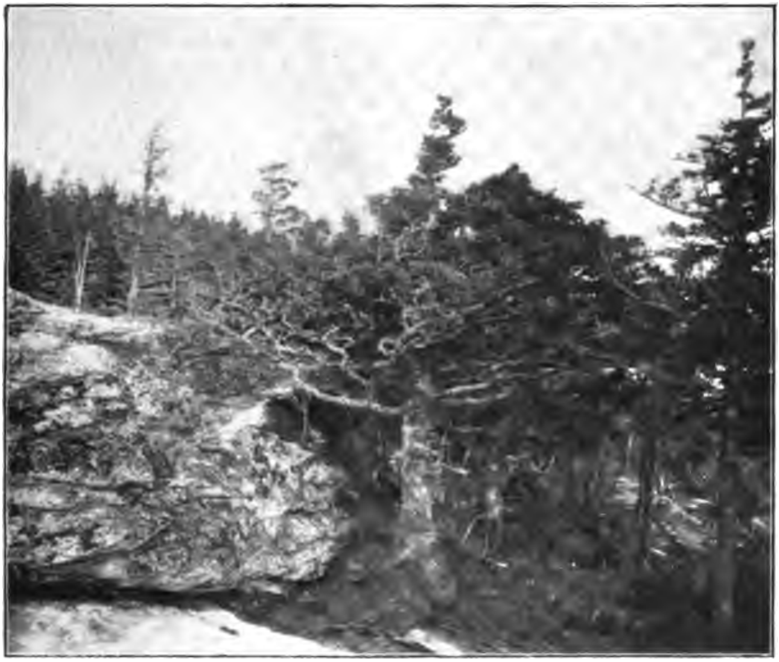
[b] During the summer and fall of 1900 extensive investigations of the forests of the Southern Appalachian region were made by the United States Bureau of Forestry, Gifford Pinchot, forester.

Notwithstanding the inroads that have been made on these forests, nowhere in the United States is there an equal area of land covered with so great a variety of valuable timber. The walnuts, tulips (poplars), and oaks grow to almost incredible size (see Pl. XI). In many localities white pine occurs in large tracts, growing to great heights (see Pl. XII) and furnishing as fine lumber as any of the pine forests of the country. Near the summits of all of the higher mountains the only growth is the balsam. Most of these trees are exposed to the cold and wind, and for that reason are small and twisted (see Pl. XIII, *A*), but where protected they grow to large size, especially in the Craggy and the Smoky mountains. Numerous varieties of rhododendrons grow on the slopes of many of the mountains, forming an almost impenetrable jungle. During the flowering season these present a most beautiful appearance, being often a mass of blossoms stretching as far as the eye can reach in every direction. Grandfather Mountain is particularly rich in this growth (see Pl. XIII, *B*), the chief species being *Rhododendron maximum*, *Rhododendron catawbiense*, and *Rhododendron vaseyi*.

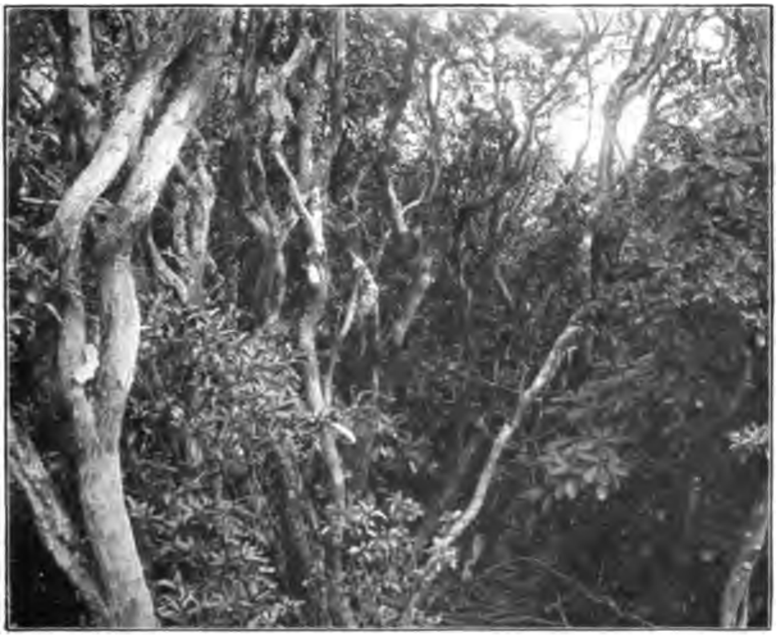
Although the region still has the finest hard-wood forests in the country, the large tracts of wild cherry and black walnut which once flourished have entirely disappeared, and the mills are now sawing cheaper lumbers, such as oak, white pine, ash, and poplar. Not many years ago the supply of walnut was so abundant that old mountaineers tell of splitting rails from walnut logs and of burning or allowing to rot the walnut stumps which to-day would bring immense sums from veneering factories. The unfortunate feature of this lumbering is that there is no discrimination in the cutting. All of the trees, large and small, are felled, and if found not suitable for immediate use they are allowed to rot on the ground. In many places the lumber companies are recutting areas which have once been gone over, and are denuding them of even the smallest trees. Some of the companies saw anything that will make a plank. In the case of the bark gatherers the wastefulness is particularly deplorable. These men fell the trees—chiefly chestnut-oak and hemlock—for the bark, and after stripping them make no attempt to use the timber. Every year hundreds of cords of bark are hauled from these mountains, and each load means that some giant of the forest lies useless on its native soil. Near the railroads it is profitable to saw the timber and haul it to the station, but the natives find that they can strip the trees and haul the bark much farther than they can afford to haul the timber. It is a mournful sight to see these immense trees lying where felled, of no use to anybody, simply marking the wanton wastefulness of man.

POPLAR FOREST.

PINE FOREST.



A. WIND-DWARFED BALSAM FIR ON GRANDFATHER MOUNTAIN, NORTH CAROLINA.



B. RHODODENDRON THICKET, NEAR GRANDFATHER MOUNTAIN.

Lumbering on a large scale has been carried on for only a few years, but in addition to the large steam mills, which are moved deeper into the forest as the timber in their vicinity is exhausted, every little creek now has one or two small water-power sawmills cutting from 500 to 5,000 feet a day. Dry kilns are built and planers are put in so that the mills can turn out finished lumber. Although by the old methods fearful inroads were made on the forests, so thorough is the denudation by the new mills that it will not take them many years to exhaust all of the timber that is worth sawing.

The four largest lumber plants operating in this section are the Watauga Lumber Company, on Watauga River; the Empire Company, in the Shady Valley; the Ritter Company, at Pineola, on Linville River; and a new company with main yards at Huntsdale, Tenn., on the Nolichucky.

The Watauga Lumber Company owns almost all of the timber in the Watauga Valley. They have built five splash dams for the purpose of floating logs down to their mill. Two of these dams are on the main river, one at Shulls Mill and the other just above the mouth of Beaverdam Creek. On Beaverdam Creek there is a splash dam about 2 miles from the mouth, and during the summer of 1900 the company removed much of the timber from the lower part of the Beaverdam Valley. About 6 miles up Laurel Creek they have another splash dam, and are now cutting the timber in that region. The fifth dam is on Elk Creek, just below the big falls. They have not commenced lumbering there yet, but they own all of the timber. At Shulls Mill the company has built a tramroad up in the mountains to haul their logs to the river. They cut only the white pine and the poplar, because of the distance the logs have to be splashed. They now have thousands of logs all along the river from Shulls Mill to their mill below Elizabethton.

The Empire Company started work in the Shady Valley during the summer of 1900. They have put up a large mill and timber pen on Beaverdam Creek, and later will put in a dry kiln. The mill is to be run by steam. The Holston Valley Railroad is being built from Abingdon, Va., for the purpose of getting this lumber out. The railroad follows down the South Fork of Holston River to the mouth of the Laurel Fork, then up the Laurel Fork and Beaverdam Creek. This is considered one of the finest timber regions in the mountain section, consisting mostly of white pine and spruce, with a very little hard wood, mostly chestnut. The land being very fertile, the trees have grown to great size, being nearly 100 feet to the first limb. Up to the present time the timber in this valley has been almost untouched, on account of the long haul over the mountains to a railroad.

The Ritter Company, at Pineola, has had its mill in operation about a year. It is run by steam, and has a capacity of 50,000 feet a day. Their timber pen is on Linville River, and the logs are brought to it by a narrow-gage railroad, which also carries the timber to Johnson City, Tenn., by way of Cranberry, N. C. The tract of this company, which contains some very fine white pine, extends from Pineola to Linville Falls, on both sides of Linville River, and includes most of the timber on Jonas Ridge.

The Ohio River and Charleston Railroad has been constructed from Johnson City, Tenn., up the valley of Nolichucky River as far as the mouth of Caney River, and a large lumber yard and shipping point have been established at Huntsdale, Tenn. A number of steam sawmills have also been built on the slopes of the Black Mountains. These mills are temporary structures and will be moved from point to point to avoid long hauls of the logs. The lumber is hauled to Huntsdale for shipment. Huntsdale has sprung up on the banks of the Nolichucky like a western mining town, and is not yet on maps of the region. The owners expect to extend the railroad very soon. It is said that they have bought 1,000,000 trees and are still increasing their purchases.

Several other companies are doing considerable lumbering. A company in Bristol has built a railroad to transport timber from the mountains south of Bristol across the South Fork of Holston River.

The many wood-working establishments on the Tennessee side of the mountains use considerable lumber, and close to the railroad on that side much soft wood is cut for the pulp mills in Bristol and other places.

Despite the great inroads on the forests in this region, many large areas have not been touched. The timber near the tops of all of the higher and steeper ridges still remains. This is particularly noticeable in the area between the South Fork of Holston River and the Watauga, where, except in the Shady Valley, which is now being cleared, all the timber that could easily be reached is gone, and only that at the tops of the steepest mountains remains. Three especially large areas, however, have not been cut, namely, Grandfather Mountain, the Black Mountains, and the long strip of land on both sides of Linville River. Grandfather Mountain is owned by the Linville Improvement Company, and it is not likely that they will permit any lumbering. The variety of trees in this area is greater than in the other regions, being hard woods near the base of the mountain and fir near the summit. The Black Mountains have escaped the lumberman only because of the difficulty of removing the logs and getting the lumber to market. Since the completion of the Ohio River and Charlestown Railroad to Huntsdale, however, several mills have started work around the bases of those mountains, and it will not be long before the timber is cut well up the sides.

On both sides of Linville River, from just below Linville to Beech Bottom, there is a very large strip of land containing exceptionally fine timber which has not been cleared of even the most valuable trees. The upper end of this strip, however, is owned by the Ritter Company, and they are clearing the area, as already mentioned. Their tract extends from just below Linville nearly to Linville Falls, and contains some especially fine white pine. The next strip, extending from a half mile above the falls to 3½ miles below them on each side of the river, and containing 51,000 acres, is owned by the Morganton Improvement Company. The next lower area, running down the river to Beech Bottom, belongs to the Cheever Improvement Company. The two latter tracts are very rich in white pine, poplar, ash, oak, hemlock, spruce, and the linn or linden.

Three railroads have been surveyed to run through this district—one from Bristol to Lincolnton, another from Cooks Gap to Lenoir, and the third from Collettsville, on John River, to Cranberry, to connect with the narrow-gage railroad running to Johnson City, Tenn. If these railroads are built the timber in the vicinity will soon be cut, leaving the ground bare, as it is along the other roads.

The unfortunate feature of the lumbering is that the ground is completely stripped of trees and then is left without cultivation. The slopes are often too steep for successful farming, and in many places the top soil is washed off and the hillsides become more or less gullied by the water rushing down the mountains.

Great as has been the havoc wrought by the lumberman, his part in the forest destruction has been small when compared with that of the clearing of the land for agricultural purposes and with forest fires. Too often the farmer, instead of trying to improve the soil in the valley, makes additional clearings on the mountain sides. Owing to the steepness of the slopes, the productiveness of the hillside fields is short lived. After the trees have been girdled and the underbrush destroyed the land can be planted in corn for one or two years, then in grain for a year, and then in grass for one or two years, after which it can be used as pasture land for a year or two, until, with increasing barrenness, the grass gives place to weeds and the weeds in turn to gullies.

Forest fires have been one of the great curses in the Southern Appalachians, as elsewhere in the country. They were of frequent occurrence in the days of Indian occupation. Thus they have preceded the lumberman, have accompanied him, and have followed in his wake, and their work has been rendered far more destructive by the lumberman leaving brush scattered among the remaining growth in such a way that in the burning it has fed the fires.

In some regions fires have entirely destroyed the forests, especially where the soil was thin and composed largely of humus. The burning of the humus has resulted in the remaining soil being soon washed away, leaving the trees standing on the bare surface of rock to dry out and die. In other places fires have destroyed the undergrowth and the larger trees have been burned near the roots in such a way as to cause their destruction. Repeated fires in the undergrowth have exterminated the grasses and other forage plants over large areas, so that instead of improving the pasturage, which is frequently the object of starting the fires, the result has been in the course of years its almost total destruction.

That the burning of the humus and undergrowth in the forests seriously affects the flow of the streams anyone who has been in a forest during a heavy rain storm will admit. In the virgin forest the raindrops are caught by the underbrush and pass downward through the humus into the less porous soil and the rock fissures beneath, to reappear weeks and months later in the form of numberless springs. But where the underbrush and humus have been burned away much less water soaks into the soil, most of it flowing down the surface with a velocity varying with the slope, washing the soil into small furrows and gullies, causing the rapid accumulation of the water into brooks, and resulting in floods in the larger streams in the valleys below.

In New England and many of the Northern States the numerous lakes and glacial deposits of sand and gravel spread out over the hills and valleys of that region serve as a storehouse for the water and materially assist the forest cover in preserving uniformity in the flow of the streams. Indeed, they would accomplish much in that direction were the forest cover entirely removed. But in the Southern Appalachian region there are no lakes and no glacial gravels and sands, hence the water storage depends entirely upon the forests and the soil.

SOIL AND VEGETATION.

Besides the actual reduction of the earth's surface according as the rocks differ in susceptibility to atmospheric agencies, the region has been profoundly affected by the soils which the rocks have produced, for on the soils the character and amount of the vegetation are largely dependent.

The soil is naturally deep and fairly fertile even to the mountain tops, while the valleys, which have been cleared, are remarkable for their fertility. In the valley of each little mountain stream can be seen the small cabins of the mountaineers, who cultivate the narrow tracts of land close to the river and often attempt agriculture on the steep slopes of the mountain sides. Pl. XIV gives views of two characteristic mountain homes. In these houses the natives live on from generation to generation, seemingly without desire for change or betterment. When the eldest son is married he is given a portion of his father's land, which he in turn attempts to clear and cultivate, managing to eke out a scanty existence, and being, like his forefathers, well satisfied with his surroundings and his condition in life. Fruits and vegetables grow abundantly and to large size, and would no doubt be cultivated much more were it not for the lack of means of transportation. The entire region is well adapted to stock raising, which is

A.

B.

TYPICAL MOUNTAIN HOMES

SPRING ON BLACK MOUNTAINS, SHOWING DENSE PLANT GROWTH.

one of the chief industries. Years ago General Clingman wrote: "Horses and horned cattle are usually driven out into the mountains about the first of April and brought back in November. Within six weeks after they have thus been put into the range they become fat and sleek. There are, however, on the top and along the sides of the higher mountains evergreen and winter grasses on which horses and horned cattle live well through the entire winter. Such animals are often foaled and reared there until fit for market, without even seeing a cultivated plantation." This custom of turning the stock loose on the mountains still continues; and in recent years considerable attention has been given to fine stock breeding.

Many varieties of shrubs and flowering plants abound, and the region should prove a Mecca for botanists. Pl. XV (a view on the Black Mountains) will give an idea of the great variety of ferns and plants with which the mountain slopes are covered. In the foreground is one of the cool springs for which the region is noted.

According to Mr. Arthur Keith, of the U. S. Geological Survey, "the moist atmosphere is conducive to the rapid decay of the rocks, which break up chiefly under the attack of rain, frost, the roots of the trees, the underground waters, and organic acids. At first decay works in along the various partings, resulting in the loosening of large masses, which gradually become smaller, until finally nothing is left of them except clay and the more obdurate bits of rock. The rocks reach the surface over only very small patches, while in places the disintegration attains a depth as great as 50 feet. On sloping surfaces the loose material is maintained in its place solely by friction. When this is lessened or overcome from any cause, the residual matter, be it clay or rock fragments, slides down the slope until the friction is again sufficient to retain it in one position. Thus are formed immense deposits washed down from steep slopes and accumulated in the hollows and flatter places. This material gradually works its way downhill, as it is pushed along by the freezing of the water, or is rendered more unstable as the water transforms it into mud. Eventually it finds its way into the streams and is carried by slow stages into the sea.

"The chief agent which checks this process of removal is the forest cover, even though the penetrating roots and the acids due to vegetation induce rock decomposition. These same roots, however, hold the loose material in place and check its tendency to slide downhill. With this assistance loose soils are upheld on slopes fully double those which they could maintain unaided. Besides this direct hindrance to the waste of slopes by increased friction, the action of the forests is as great in another way. Loose material is washed downhill during rain storms by even the tiniest rivulets.[a] In open fields these gather in a few minutes, and form deeper and deeper channels with each succeeding storm, finally removing the loose material down to the bare rock. This process is almost prohibited by the network of roots and the cover of leaves, both living and dead, and the water concentrates into rivulets by seeping through the soils so slowly that it carries no sediment. The waters finally drain off in the hollows and small streams whose channels have been fitted by long use to withstand the attacks of rushing water.

---

[a] Pl. XVI, *A*, shows the starting of such a wash in a deforested area and illustrates the way in which this wash is checked by the growth of trees higher on the mountain side. H. A. P.

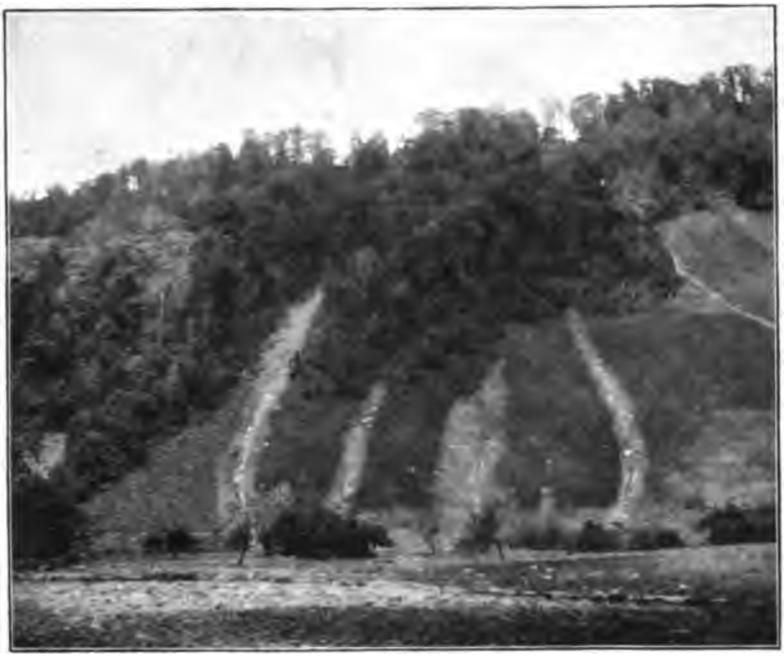
"Countless illustrations of this process can be seen during any rain storm. Streams which drain considerable areas of cleared land rise fast and become turbid with mud. Those which drain areas protected by forests rise much more slowly, and by comparison the water could be called clear, except in violent storms. This result is of course most striking at the very headwaters, the little streams rising in the fields and in the woods. The effects of this work are seen in the innumerable gullies which gash fields left to the elements for any time. In fact, unless checked by the most constant attention these gullies soon strip off the soil and clay and ruin the fields.[a] In the forests, on the other hand, one rarely sees a slope of soil not covered with vegetation, and it is only along the immediate banks of the streams that raw slopes of loose material are exposed. In short, in this region of deep residual soils the influence of the forest is paramount. It is a fact well known among the mountaineers that the soils are far more fertile when first cleared from timber than ever again. It is equally well known among the farmers along the river bottoms that the same crops have been planted there with equal success for scores of years. These latter soils, however, are refreshed from time to time by the overflowing waters, which have swept off fertile materials from the steeper slopes above. The natural fertility of the mountain soils is very great, as is abundantly shown by the dense and luxuriant forest growth. The pristine strength of the soil soon wanes in the clearings, however, and there ensues a loss which is permanent for at least a generation. To convince one's self of the existence of this condition it is only necessary to visit the region.

"In addition to the loss inflicted by forest cutting upon the steep slopes themselves great damage also results to the lands lying farther down the streams. The deep clays and underlying rocks form a kind of gigantic sponge which stores up water during its plenty. When the forests are stripped away the waters collect and run off with vastly greater speed, and much evaporates, so that not only is less stored up, but the discharge is more irregular and temporary. Destructive floods result and droughts are wider spread. Thus, viewed from the standpoint either of utility or beauty, these unrivaled forests are the keystone of the arch."

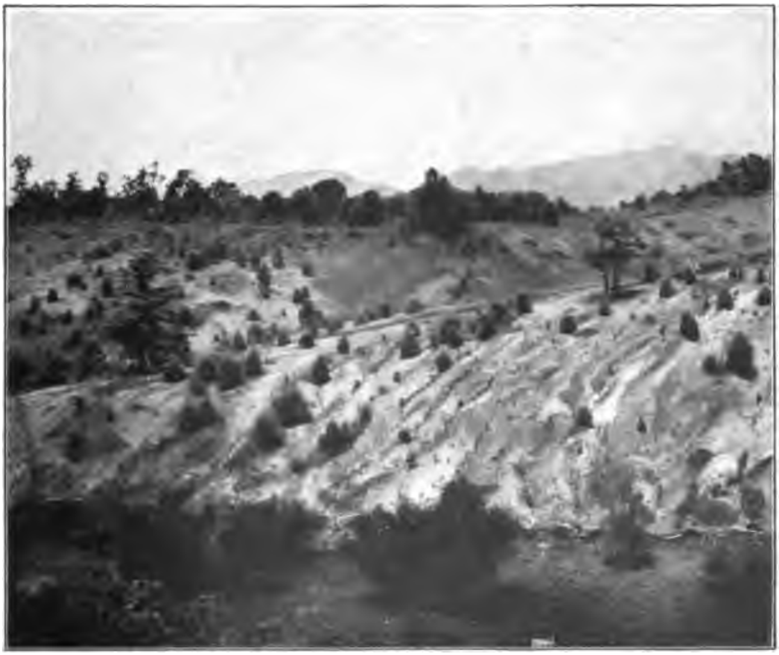
During high floods the rivers carry enormous quantities of sand and

---

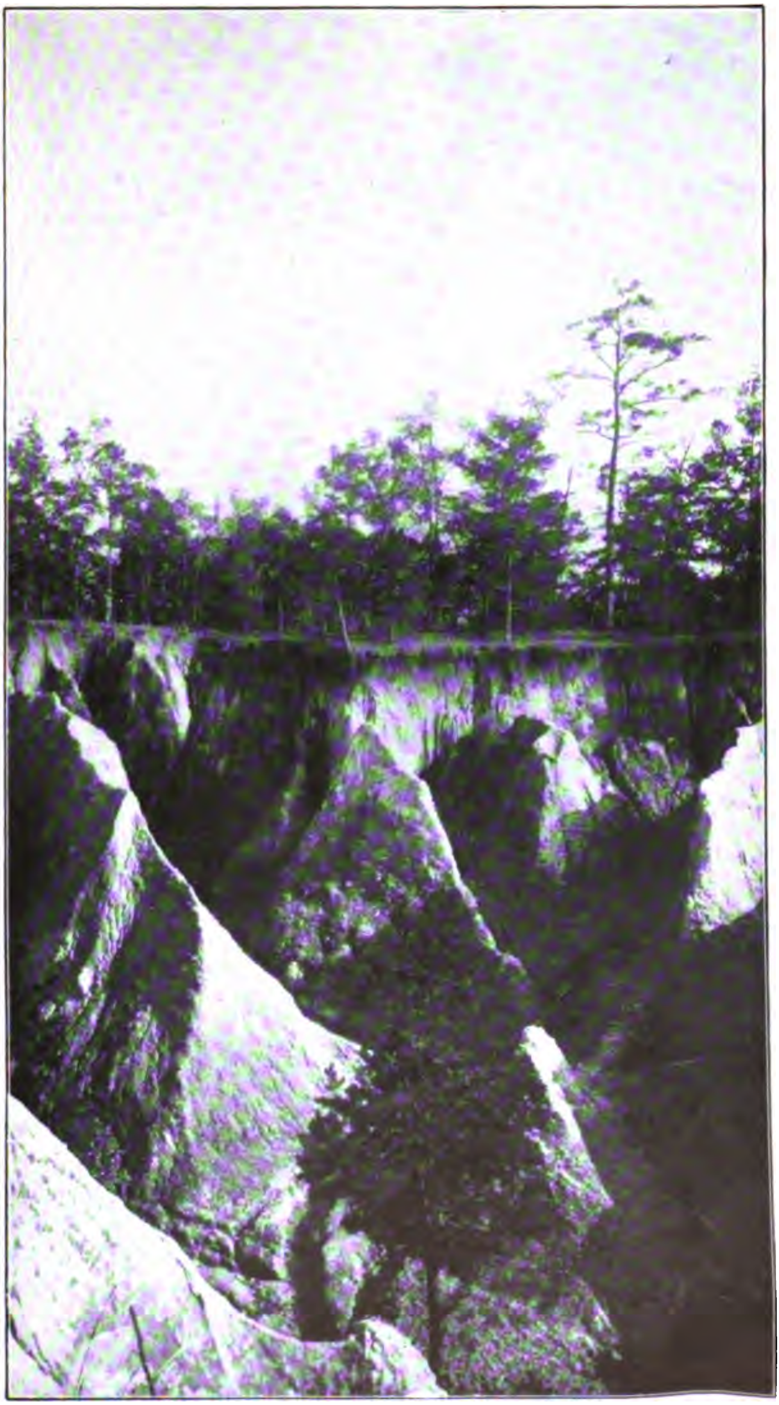
[a] See Pls. XVI, *B*, and XVII. E. A. P.



A. VIEW SHOWING BEGINNING OF WASH ON MOUNTAIN SIDE.



B. VIEW OF DEFORESTED HILLSIDE, SHOWING EFFECT OF EROSION.



WATER-WASHED GULLY IN DECOMPOSED GNEISS, McDOWELL COUNTY, N. C.

clay washed from the mountain sides. This material is deposited in great beds upon the cultivated lands along the rivers below (see Pl. XVIII, *A* and *B*), making future tilling impossible and ruining immense areas of arable land.

Inasmuch as the rivers are chiefly dependent upon their headwaters for supply it is impossible to overestimate the importance of preserving the forest cover on the mountain sides.

MINERAL RESOURCES.

No effort will be made to describe in detail the mineral resources of the region. The geological surveys of the various States and of the United States have published considerable literature on that subject, and further studies of it are now being made. Stated briefly, corundum abounds in certain localities. The mica of Yancey and Mitchell counties is widely known as among the best in the world, the deposits being so extensive as to furnish a large part of the world's supply. In a number of counties iron occurs in large quantities, and copper and other minerals have been mined to some extent. In the descriptions of the various drainage areas mention will be made of the more important mineral resources of specific localities.

HIGHWAYS.

The highways of the region are bad, having steep grades and being poorly surfaced. In many localities practically no work is put on the roads, and during certain seasons of the year they become almost impassable to wagons. This is largely due to the neglect of the inhabitants, for in most parts of the mountain districts excellent road materials exist, and with proper care and intelligence the highways could be maintained in good condition at moderate expense. Upon the mountain sides the rain water is allowed to run in the road bed, soon washing out great gullies and exposing the rocks, so that a horse is obliged to pick his way from side to side with great care and the rider to be constantly on the alert to prevent accident. Such a road is shown in Pl. XIX, *A*. The highway from Marion, N. C., to Sprucepine, illustrated in Pl. XX, is a typical mountain road of this region over which a wagon can pass, but with difficulty. In many cases, in order to avoid cutting a road on the slopes of the mountains, the stream bed is used as a highway, although usually exceedingly rough and at the time of high water dangerous to the traveler. Pl. XXI illustrates a road bed which has for years been used as a highway. Farther down the river valleys, where clays are more prevalent, the roads are often exceedingly muddy, it being a common occurrence for the wagons to sink hub deep into the mud. (See Pl. XIX, *B*.) There are a few remarkable exceptions, however, as, for example, the toll road from Linville around the base of Grandfather Mountain to Blowing Rock, known as the Yonahlossee road and shown in Pl. XXII, and the road between Blowing Rock and Boone, both of which are excellent in grade and surface and show what can be done when the materials at hand are used with skill.

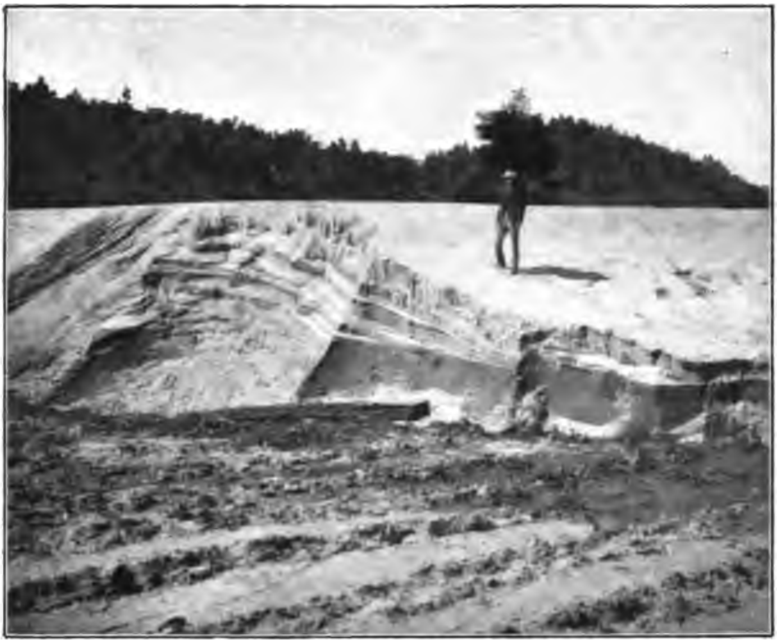
DRAINAGE BASINS.

In the course of the examination of the watersheds and the general investigation of the flow of the streams in the Southern Appalachian region which were carried on during the summer of 1900, many measurements of flow were made on the larger streams and on most of their upper tributaries, the results of which are contained in this report. The small Price meter was used in making measurements. There being few bridges in the region most of the measurements were made by wading. It was therefore impossible to make gagings of many of the streams at the time of high water.

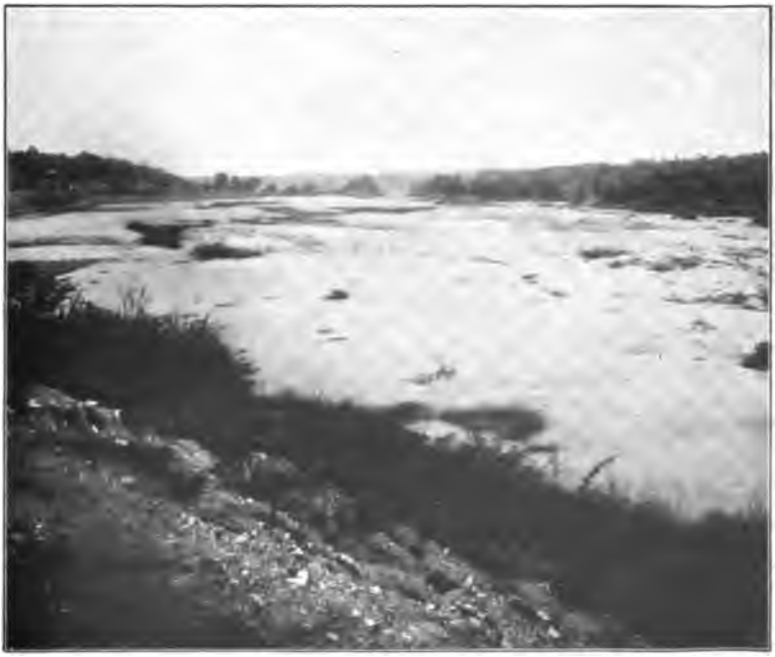
In some respects the season was peculiar. Rain was abundant during June and the streams were moderately high during the early part of the summer. Later, however, very little rain fell, and most of the rivers and their tributaries were at an extremely low stage, as low, in fact, as they have been for a number of years. An effort was made to make more than one measurement at the same point on each stream. When the first measurement was made a bench mark was established, and the relative height of the water surface was measured at each successive gaging. Examinations were also made for high-water marks, and when the annual fluctuations of a stream could be determined they were noted. By means of these data a knowledge of the flow of the streams at various stages and of the relation that exists between the rise of the streams and their discharge can be obtained, though of course the only definite information we have is the discharge at the time of measurement.

On the larger streams gaging stations were established, as is the custom of the Survey, the height of the water surface being read daily on the gage and recorded by a local observer, and the measurements, which were made as often as practicable, being referred to the same gage. With these data a curve was plotted, using the gage readings as ordinates and the stream discharge, in cubic feet per second, as abscissæ. From this curve, the mean of the daily gage readings being known, the approximate daily discharge was interpolated. This method is described in detail in the annual reports of the Survey and in Water-Supply Paper No. 56.

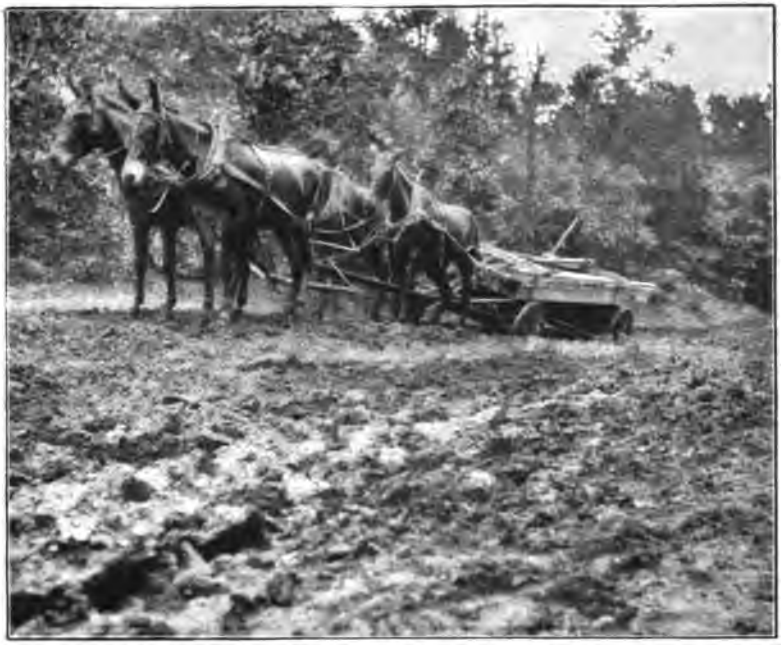
The great difficulty encountered at these stations, which are on mountain streams, was to obtain measurements at the time of high water. After a rain the rivers rise rapidly, and as they fall as quickly, unless a person is near the station the high water will have passed before he can reach the point of measurement.



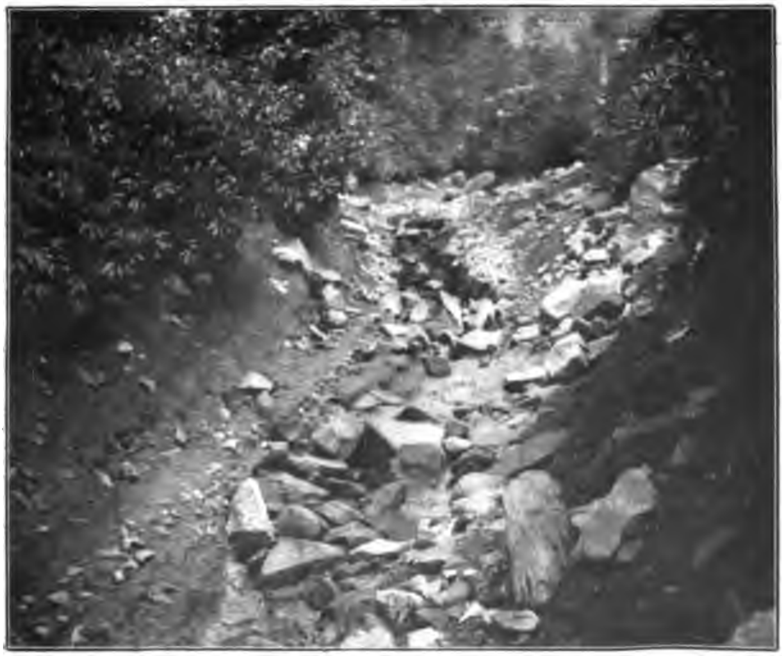
A. SAND AND CLAY DEPOSIT IN VALLEY.



B. SAND DEPOSITED UPON FARMING LAND BY RIVER FLOOD.



A. WATER-WASHED COUNTRY ROAD IN MITCHELL COUNTY, N. C.



B. UNIMPROVED ROAD IN VALLEY.

The following is a list of the gaging stations established in the basin:

Gaging stations established during 1900 on streams in Southern Appalachian region.

Stream.	Location.	Date established.
		1900.
New River	Oldtown, Va	August 5.
South Fork of New River	New River, N. C	July 29.
North Fork of New River	Weaversford, N. C	Do.
Yadkin River	Siloam, N. C	August 3.
Catawba River	Morganton, N. C	June 19.
John River	do	Do.
Linville River	Bridgewater, N. C	July 3.
Broad River	Dellinger, S. C	August 30.
South Fork of Holston River	Bluff City, Tenn	July 17.
Watauga River	Butler, Tenn	August 11.
Roan Creek	do	Do.
Elk Creek	Lineback, Tenn	August 5.
Nolichucky River	Chucky Valley, Tenn	September 20.
Pigeon River	Newport, Tenn	September 4.
French Broad River	Oldtown, Tenn	Do.

Besides the foregoing stations, which were established during the summer of 1900, the following gaging stations have been maintained for several years upon streams flowing from the Southern Appalachian Mountains:

Regular gaging stations of the Geological Survey on streams flowing from the Southern Appalachian Mountains.

New River at Radford, Va., and at Fayette, W. Va.
James River at or near Glasgow, Buchanan, Cartersville, and Holcomb Rock, Va.
Roanoke River at Roanoke, Va., and at Neal, N. C.
Dan River at South Boston, Va.
Staunton River at Randolph, Va.
Yadkin River at Salisbury and Norwood, N. C.
Catawba River at Catawba, N. C., and at Rockhill, S. C.
Broad River (of the Carolinas) near Alston, S. C.
Saluda River at Waterloo, S. C.
Tallulah River at Tallulah Falls, Ga.
Tugaloo River near Madison, S. C.
Savannah River near Calhoun Falls, S. C., and at Augusta, Ga.
Oconee River near Dublin, Ga.
Chattahoochee River at Oakdale and at West Point, Ga.
Coosawattee River at Carters, Ga.
Oostanaula River at Resaca, Ga.
Coosa River at Rome, Ga., near Riverside, Ala., and at locks Nos. 4 and 5, Alabama.
Toccoa River near Blueridge, Ga.
Nottely River at Ranger, N. C.
Hiwassee River at Charleston and Reliance, Tenn., and at Murphy, N. C.
Tennessee River at Chattanooga and Knoxville, Tenn.
Little Tennessee River at Judson, N. C.
Tuckasegee River at Bryson, N. C.
French Broad River near Asheville, N. C.

These stations cover every stream rising in the Southern Appalachian Mountains. Results of measurements will be found in the annual reports of the Survey.

HOLSTON RIVER.

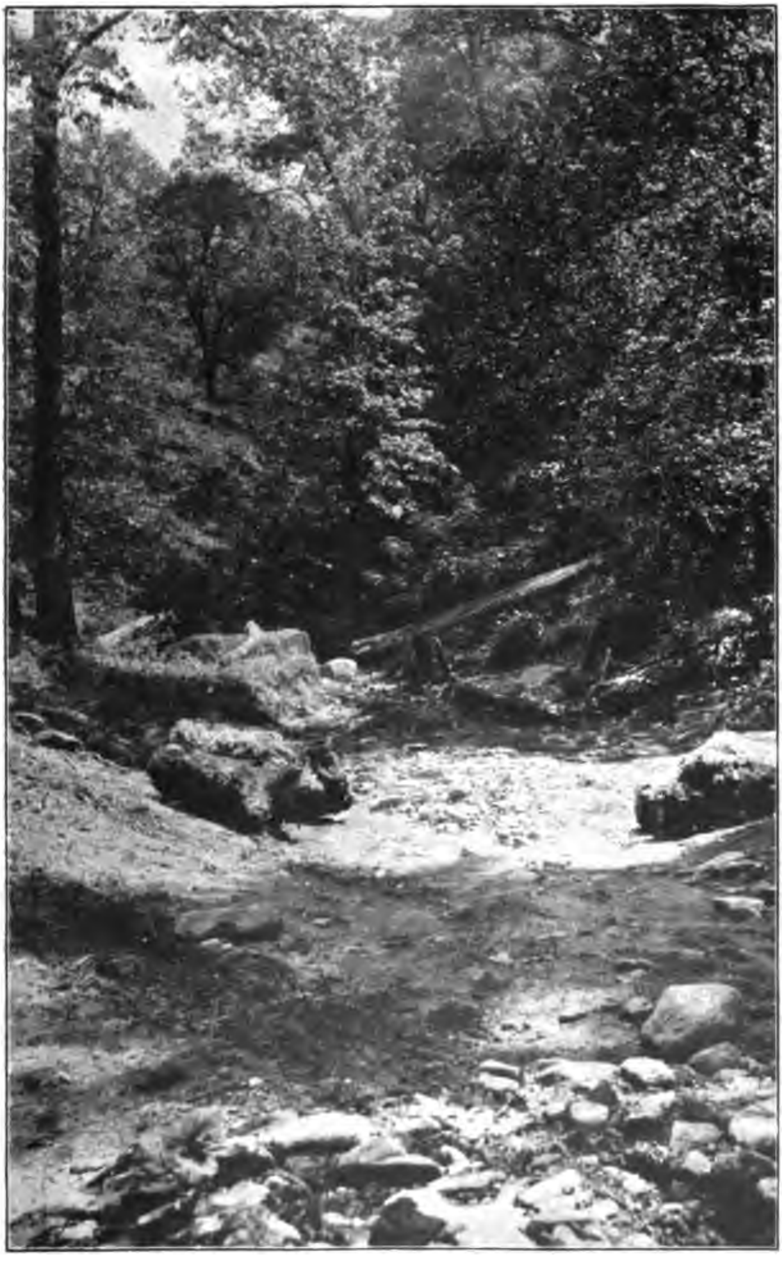
PHYSICAL FEATURES.

The areas drained by Holston River comprise the basins of the North, South, and Middle forks of that stream, the Watauga, the Nolichucky, and the French Broad, including parts of southwestern Virginia, eastern Tennessee, and western North Carolina. The river is one of the largest of the streams which form the great Tennessee River. It rises along the western slopes of the Blue Ridge, in Smyth and Bland counties, Va., in three forks, known as the North, Middle, and South forks, respectively. The North Fork, from its position, receives no tributaries rising within any of the areas proposed for the projected Appalachian National Park, and for that reason, in view of the very large area necessary to be covered during the field season and the limited time in which to perform the work, it was not investigated. The areas drained by the Middle and South forks were quite thoroughly studied, and many direct instrumental measurements were made of their flow and of the flow of all streams tributary to them whose discharge was sufficiently great to admit of the use of a current meter, the minimum limit being, roughly, a little less than 1 cubic foot per second, depending largely on the form and character of the bed of the stream.

The physical conditions of the drainage basin vary greatly, the character of the country ranging from the gently rolling plain of the South and Middle forks, with its smooth, rounded, and grass-covered hills, to the grandest and mightiest mountain masses to be found east of the Rocky Mountains, such as the Unakas and the Black Mountains, with their numerous peaks rising more than 6,000 feet above sea level, and with steep and rocky slopes still clad in virgin forest. There are wide variations in the soil and in the general geologic conditions and structure, considerable variation in temperature and rainfall, and still wider variations in the character of the streams of the area, which include the brawling mountain torrents fed by perpetual springs, the puny wet-weather streams of the slate country, and the subterranean streams of the limestone regions. The entire area is part of the great Mississippi slope, of which the eastern boundary is formed by the Blue Ridge Mountains, on which all of the streams of this area rise, those of Virginia flowing to the southwest, through the great Valley of East Tennessee, those from North Carolina flowing to the northwest, through the Unakas, in grand and deep gorges and down the valley slopes to their union with the main stream.

The Unaka chain, the most prominent natural feature within the

MOUNTAIN ROAD NEAR SPRUCEPINE, N. C.



ROAD IN STREAM BED.

area, is a long range, the most massive of the Appalachians, its high crests forming the boundary between North Carolina and Tennessee. It is for the most part one single ridge, but occasionally it spreads out into a series of from two to four parallel ridges. The chain is continuous except that it is intercepted by the deep and rocky cuts of the tributaries of the Holston and the Tennessee. In Virginia it unites with the Blue Ridge. It forms large parts of Johnson, Carter, Washington, Greene, Cocke, and Unicoi counties in Tennessee. In Johnson County the ridges lie in such a manner as to completely encircle the great cove of the county, and in Carter County they nearly inclose the valleys. It has been said that the chain is a belt of parallel ridges, but in most of the Tennessee part of it the ridges are two in number, one being the main axis of the chain, the other lower and lying along the foot of the slope, though generally separated from the main range by long coves. This typical character does not always hold good, however, the greatest departure being in the country to the northeast of French Broad River.

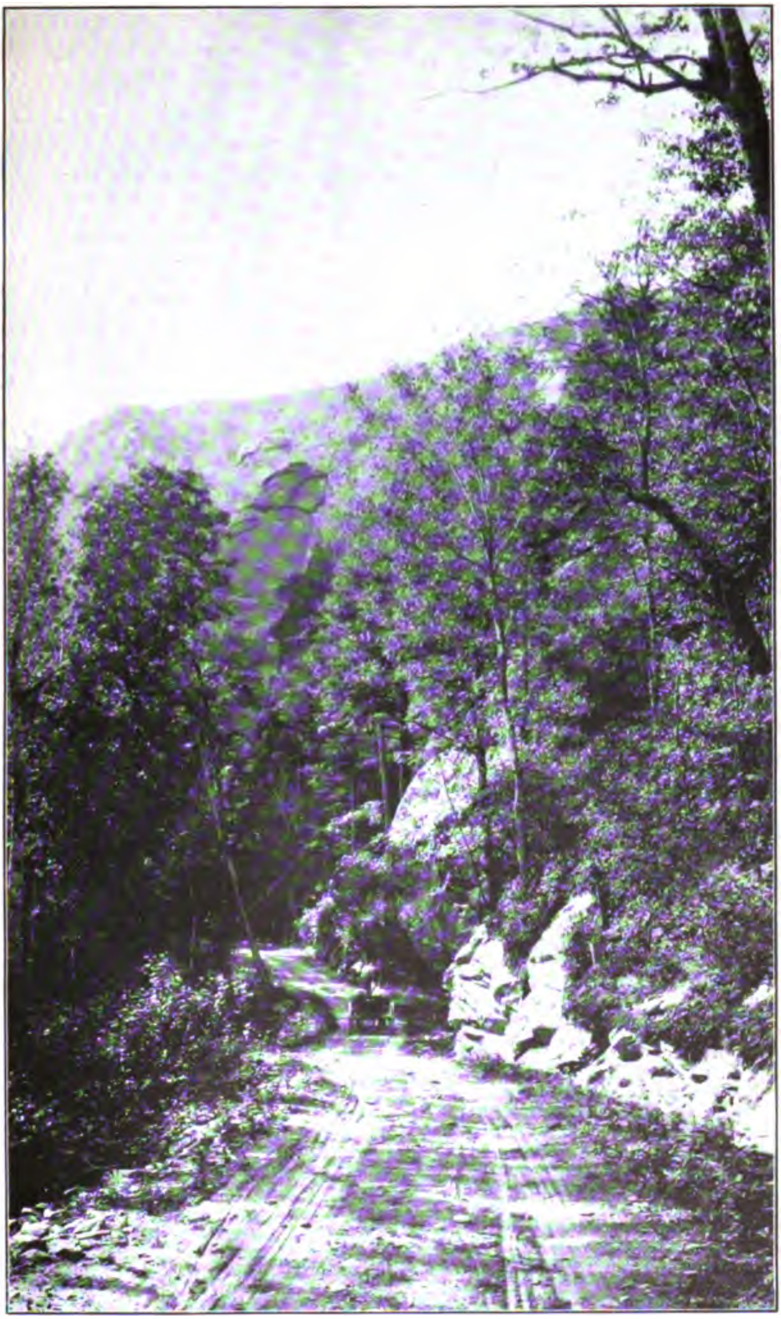
In the northeastern corner of the State, north of Watauga River, in Johnson and Carter counties, the Unakas divide into three distinct ranges separated by wide and beautiful valleys. Seen from some points these ridges appear parallel, but in reality they are convergent toward the north, and near the Virginia line the Holston and the Iron mountains, the most western of the diversions, converge, and farther on, in Virginia, the two ranges unite in the long chain known as the Iron Mountains. The most easterly of these three ranges is the Stone Mountains, a long series of crowded ridges, along the crest of which runs a portion of the State line, extending from south of the Watauga and culminating in the grand and conspicuous summit of Whitetop. The middle range is the Iron Mountains, a long, straight ridge extending through Johnson and Carter counties—a portion of it forming for a long distance the boundary line between those counties—being separated from the Stone Mountains by the valley lands of the former county. Watauga River and Doe River have cut through this range, but it continues to be well defined until the southern part of Carter County is reached, and there it sinks away. South of the Watauga it is separated from the mountains on the east by a long and narrow valley known in its wider portion as Doe River Cove. The last and most westerly of the ridges is the Holston Mountains, which run out abruptly from the other ridges and terminate as abruptly a few miles north of Elizabethton, Tenn. They are separated from the mountains on the east by the curious, very elevated basin called Shady Valley and by the valley of Stony Creek.

As a rule the Unaka ridges are forest clad. The higher summits, however, are frequently destitute of trees, owing perhaps to the high altitude and the consequent low temperature, but more probably to peculiarities of the soil. Such summits are called balds. Sometimes they are a mile or more in diameter, and sometimes a chain or succession of them occurs along a ridge, forming a continuous bald for several miles. Roan Mountain is a bald of the latter class, and there are several others like it in the range. The most magnificent views in the mountains are obtained from these peaks.

Lying to the west of the Unakas is the great valley known as the Valley of East Tennessee. This broad and beautiful basin is a southward continuation of the famous Valley of Virginia. In Tennessee it has an extreme width of more than 50 miles. It is drained by the Holston and its tributary streams. The portion of the valley covered in the course of this investigation embraced parts of Sullivan, Carter, Johnson, Washington, Greene, and Cocke counties. The topography is composed largely of a series of parallel ridges, the axis extending in a northeast-southwest direction, making the country very rolling when viewed transversely. One of the most marked peculiarities of the region is the short and narrow ridges of slate which are apparent here and there over the area, sometimes occurring in short chains of slaty knobs. In Washington, Greene, and Cocke counties the valleys partake of the nature of the ridges and are short and broken. There are wide variations in the width of the stream valleys, some being sharp and V shaped, others several miles in width and very beautiful and fertile. One of the largest of the valleys is in Johnson County—Johnson County Cove, as it is sometimes called. Its form and position can be seen by reference to almost any map of the area. Below Mountain City it is divided lengthwise by Doe Mountain, an isolated sandstone ridge, but the parts are united again in the valley of the Watauga, which is said to have a larger area than any other valley of similar elevation in the State. It narrows to a point a short distance from the Virginia line, and is entirely inclosed by mountains, the Stone Mountains being on the east and south and the Iron Mountains on the northwest.

Lying between the Holston and the Iron mountains, just before they unite in Virginia, is the elevated basin called Shady Valley, also situated in Johnson County, and being much higher than the great valley just described, but having a much more limited area. The elevation is so great that the flora partakes of the character of that found in the northern regions of Canada. Iron of good quality and very fine white pine and spruce are found here. This valley is more fully described on pages 65 to 66, in the description of the area drained by Beaverdam Creek.

The rivers of the Valley of East Tennessee are wide and shallow, the waters clear and beautiful, and the tributaries numerous. There are two general directions of flow, the tributaries flowing to the northwest or the southeast and the main streams flowing to the southwest. The valley floor throughout is very level to gently rolling, composed of small and rounded hills with gentle, grass-covered slopes, leaving



YONAHLOSSEE ROAD, AROUND THE BASE OF GRANDFATHER MOUNTAIN, NORTH CAROLINA.

broad areas of level meadows or bottom land between them and dotted over with small tracts of hard-wood trees. From this general level the transverse ridges as a rule rise gently, although they are sometimes very rough and rugged and are almost entirely forested.

The area drained by Holston River in Virginia is entirely within the limits of Washington and Smyth counties, being the southeastern half of each county. The extreme southern and southeastern parts of the area are covered by the northward extension of the great Unaka chain known as the Iron Mountains. The extreme eastern part is covered by the slopes of the Blue Ridge and its outliers, the Pond and the Brushy mountains. On the north it is closed in by the slopes of Walker Mountain, a long ridge which separates the watersheds of the North and South forks of the stream. The general characteristics of these mountain areas are similar to those previously described for the Unaka chain in Tennessee, except that the peaks rise to less heights and are completely wooded. The geologic structure is, however, different, many of the mountains being capped with sandstone, the prevailing rock of the valley floor being limestone. The valley itself is much more broken, and in its upper part contains a much smaller portion of cleared land than the areas farther to the south, the natural consequence of the changed topography. However, the strip of level land bordering the South Fork on the south, the entire area between the South and Middle forks, except the slopes of the Pond and the Brushy mountains, and the area to the north of the Middle Fork as far as Walker Mountain are well situated for agricultural and stock-raising pursuits, are almost entirely cleared, and are in a high state of cultivation, being held at a very high valuation.

The part of the watershed in North Carolina, being the areas drained by the Watauga, Nolichucky, and French Broad rivers, is included in the counties of Watauga, Yancey, Mitchell, Madison, Buncombe, Henderson, and Transylvania, and is described at length in connection with the drainage basins of those rivers. The last four counties comprise the watershed of the French Broad. The first three counties—Watauga, Yancey, and Mitchell—occupy the entire width of the transmontane plateau lying between the western slopes of the Blue Ridge and the Unakas, and their surface is a bewildering confusion of mountain chains and spurs extending in every direction, without order or plan, and inclosing short and narrow valleys and inconsiderable areas of cleared land, except along some of the larger streams.

One of the distinguishing characteristics of the whole basin drained by Holston River is the occurrence of small closed basins or sinks, which are found in great numbers on the low divides between the various tributary watersheds. They are so numerous, in fact, that in many localities it seems impossible that any of the rainfall over areas of a square mile or more can find its way into the streams. Certainly there are no channels visible, and in many cases water was seen standing in pools from 50 to 100 feet in diameter, indicating that there is no subterranean passage through which the water finds its way to the streams. Other sinks are dry, except after heavy rains. In some instances the farmers have rendered the bottoms of these natural basins impervious, and the collected water is used for cattle.

Springs are numerous over all the basin, ranging in size from a discharge of several cubic feet per second to less than a gallon per minute. Many of the smaller streams seem to be fed entirely from this source. In this connection may be noted the fact that a number of streams which at some point in their course sink below the surface of the ground, after flowing there for distances varying from a few yards to a half mile or more reappear on the surface. Some streams were noted which while discharging no water into the main stream carried a considerable quantity a short distance above their mouths, the water sinking gradually into the earth as the river was approached. It is said that the Middle Fork loses a quantity of water in this way, and from the character of the country rock this seems by no means improbable.

RAINFALL.

Little definite information can be given regarding the annual rainfall in this basin, but it is well known that throughout the region there is no lack of moisture, showers frequently falling on the mountains when there is not a cloud over the valley. The rainfall in the valley to the west is between 40 and 45 inches per annum, and that on the mountains is certainly greater. Throughout all the area covered by the investigation there is a lack of records whereby the rainfall can be even approximately determined, most of the records obtainable being very fragmentary. Those at Knoxville best represent the average condition prevailing over the valley, though the Chattanooga records may be of service in determining the average rainfall. The maximum precipitation recorded at Knoxville is 73.8 inches per annum, which is 146 per cent of the mean, and up to 1896 the minimum was 37.4 inches, or 74 per cent of the mean. At Chattanooga the maximum is 68.1 inches per annum, or 126 per cent of the mean, and the minimum is 37.2 inches, or 69 per cent of the mean. It may be stated that the variation between the maximum and minimum rainfall is at least as great as this throughout the region, the precipitation in dry years being somewhat less than 50 per cent of the mean.

Droughts are rare and as a rule of short duration. The most notable one occurred in the summer and autumn of 1900, when throughout the entire country, both in the valleys and on the mountains, the drought was very severe and long continued, producing the lowest known stage of flow in all of the streams. During the winter the higher summits are almost entirely covered with snow

AGRICULTURE.

As might be expected from the comparatively scanty population and the inadequate transportation facilities, agriculture and stock raising are the principal pursuits. In the valley of Holston River, where the country is comparatively level, there are many fine farms, which are held at a high valuation, and the community seems extremely prosperous. Although the areas drained by the Watauga and the Nolichucky are rough and mountainous, yet the lower slopes afford a fine cattle range, and the valleys are sufficiently extensive to produce the necessities of life for the inhabitants.

MINERALS.

The mining possibilities are very large, although little has been done to develop this source of wealth. In the localities where mines have been opened the work seems to have been carried on in a very spasmodic way. Iron ore of great purity is found in abundance in many places, and has been mined to a considerable extent at some localities, the ore being reduced at the furnaces at Bristol, Johnson City, Embreville, and Cranberry within the basin, or shipped to Pulaski and near-by points outside of it. Copper, lead, zinc, fluorspar, gypsum, gold, salt, barytes, mica, corundum, and gem stones all occur in quantity, and some have been mined at large profit.

LUMBER.

The lumber interests also are of great importance, the area containing many large tracts of fine timber, from which several large sawmills draw their supplies, while small portable mills are found over all the area. A large amount of tan bark is stripped near the railroads, the stocks being sometimes worked into cord wood, but more often allowed to rot where they fall.

TRANSPORTATION.

The transportation facilities over the greater part of the area are pitifully inadequate. The Norfolk and Western Railroad skirts the northern edge of the basin of Holston River proper, the Knoxville branch of the Southern Railway follows along the French Broad, there is a narrow-gage road from Johnson City to Cranberry, a small standard-gage road has been constructed from Bristol to Butler and is now being extended up the valley of Roan Creek toward Mountain City, while another road is being built from Abingdon to Damascus, from which place it will extend up Beaverdam Creek and into the Shady Valley, and the Ohio River and Charleston Railroad has recently been extended along the Nolichucky as far as the mouth of Caney River. In by far the greater part of the area, however, the only means of transportation is by wagons drawn over the mountain roads, which are generally very rough and steep.

SOUTH FORK OF HOLSTON RIVER.

PHYSICAL FEATURES.

The South Fork of Holston River rises on the western slopes of the Blue Ridge, in Smyth County, Va., between the slopes of the Brushy Mountains on the north and the Iron Mountains on the south. It is formed by the junction, in a broad stretch of valley land, of Slemp and Cressy creeks, and flowing in a general southwesterly direction is joined by the Middle Fork about 6 miles southeast of Abingdon, Va. The stream below this junction and until the junction with the North Fork is still known as the South Fork. Below the latter junction it is known as Holston River.

The headwaters of the South Fork are at an altitude of about 2,800 feet, those of the Middle Fork at an altitude of about 2,900 feet, the elevation at the junction being about 1,800 feet. The altitude at the junction of Slemp and Cressy creeks is about 2,575 feet. The distance between the latter junction and the junction with the Middle Fork is about 29 miles in a straight line, and the average slope of the country about 27 feet to the mile. Following the course of the river, however, this distance is about 36 miles, and the average fall between 21 and 22 feet to the mile.

Although the basin is, broadly speaking, a plateau, it is not to be inferred that it has not some very sharply marked mountain ridges. The axes of these ridges extend in a northeast-southwest direction, approximately parallel to the course of the principal streams, and the buttressing spurs of the Iron and the Stone mountains serrate the southern edge with a series of high and jagged ridges. Away from these, however, the country is composed of a series of low, broad swells and wide, flat valleys, all of the slopes being gentle and covered with grass not unlike the famous blue grass of Kentucky. The soil seems very fertile, and good crops of corn, wheat, oats, and hay are produced.

For convenience in describing this large area, the country has been divided as follows: (1) Area drained by the South Fork below junction with the Middle Fork; (2) area drained by the South Fork above junction with the Middle Fork; and (3) area between the South and Middle forks. The area drained by the Middle Fork is described on pages 69 to 77.

AREA DRAINED BY THE SOUTH FORK BELOW THE JUNCTION WITH THE MIDDLE FORK.

This area lies entirely within the eastern half of Sullivan County, Tenn., and to the north and east of Bluff City, the western limit of the investigation. Throughout the basin occur many small closed basins or sinks, ranging in size from perhaps 50 feet in diameter to areas covering several acres. In many of them water was seen standing to a depth of several feet. Others bore traces of having recently contained water, while others were well drained. These basins are not indicated on any map of the area, and computations of run-off will be much complicated by them, as the amount of water kept back from the streams is a totally unknown quantity. The country rock is a limestone, much jointed and laminated in places, very massive in others, and these sinks are characteristic of that formation. Ledges of slate are numerous. The limestone is gray to black in color, and strikes to the northeast, the dip being frequently as great as 85 degrees. It is of very good quality, being suitable for quarrying into building stone, and a considerable quantity is used locally, none, however, being quarried for shipment, so far as could be learned. Perhaps the the most important use to which this stone is put is for flux at the various blast furnaces. Small amounts are also burned into lime, which is used in the local building operations or is applied to the land. A small quantity is also used as a road material, but this quantity is very small indeed, for little attention is paid to the roads, which as a rule are poorly graded and ill kept. The soil is in places a red clay impervious to water, but seems for the most part to be a gray, yellow, or brownish loam, and is very fertile.

The country on the south side of the river near Bluff City is preeminently suited to agriculture and to stock raising, being made up of a series of very low and broad ridges and small swells or hills rising from 25 to 30 feet above the level of the valleys between, all forming the surface of a plateau elevated 200 feet or more above the river level. The hillside slopes are gentle, ranging from 5 to 10 degrees, and there are large areas of level land. The general impression of the country when viewed from a distance is that of a plain, but at closer range it is seen to be very gently rolling. By far the greater portion (about 80 per cent) of the land is cleared and either cultivated in corn or wheat or sodded in grass, the areas of each being about equal. The forest growth occurs in small and segregated areas, too small to have much effect on the run-off from the surface. The character of the growth varies, being in some parts almost exclusively pine, while in others and over the larger part of the area oak and chestnut are the predominant trees. Many other varieties, however, are found in abundance, and occasionally the finer cabinet woods, such as walnut, curly maple, and curly birch. As the main stream is approached the country becomes much rougher, the small stream valleys being more deeply carved and the hillside slopes steeper. The descent from the broad upland plateau to the river plain several hundred feet below is very steep.

Ascending the river the uplands for several miles above Bluff City are similar to those described, except that possibly the proportion of cleared land is slightly less; but it is estimated to be about 75 per cent of the area, and at least half of it is in grass. Throughout this part of its course the river runs in a channel carved through the soft limestone country rock and into the harder and more resistant slates, producing a very rough bed, the slate being much jointed and laminated and projecting in jagged ridges across the course of the stream; but the fall seems well distributed, there being little noticeable concentration at any point.

Going up the river the portion of cleared land seems to gradually decrease, until near the mouth of Weaver Creek it has diminished to one-half or less. This is a consequence of the greatly changed topography, the plateau character of the uplands having been largely lost, sharp and rugged forest-covered hills having taken the place of the small, round, grassy knolls and wide, level bottoms seen farther down the stream. Near the mouth of Weaver Creek the mountains close in on the river, and from that point to and above the mouth of Morrills Creek all of the basin lying to the south of the stream is very rough. There is no arable land along the river, and the hills are wooded to the top.

On the south side of the stream the country draining into the river below the junction with the Middle Fork is composed of the basins of Jacobs Creek and Denton Valley Creek. Near the river the country is more gently rolling than farther downstream, and as a consequence is more largely cleared, but of the whole area drained by Jacobs Creek probably only about 10 per cent is cleared, most of it near the mouth. A short distance up the stream the country becomes broken and rough and is largely in woodland. For about 3 miles above the mouth of Denton Valley Creek a considerable portion—possibly one-third—of the land is cleared, being largely devoted to grazing. The hillside slopes vary from 15 to 30 degrees. These slopes show a great deal of exposed limestone. Above this 3-mile stretch the country rapidly becomes very rough and rugged and is totally forested.

On the north side of the stream the topography differs slightly from that on the south side, consisting entirely of small hills and rounded swells, with a larger proportion of cleared land, ranging from about two-thirds over the lower part of the basin to three-fourths or more near the Virginia line and around Bristol, while over some of the small drainage basins, such as that of Sinking Creek, more properly known as Beidelmans Creek, from 85 to 90 per cent of the land is cleared and under cultivation or in grass or pasture. The same is true of the area drained by Thomas Creek and of the area known as the Holston Valley, the country being almost level and almost entirely grass covered, the soil being for the most part gray and porous, though some areas of red clay were seen. On the north side of the river, near

Bluff City, zinc is found in paying quantities and mines are now being opened. There are numerous deposits of iron ore throughout the area, and the same is said to be true of all the counties bordering the Unaka Mountains. Over the valleys of Spring Creek (the first tributary entering from Virginia), Wolf Creek, and Fifteenmile Creek the general character of the country is the same as that just described, probably more than 75 per cent of the area being cleared, the soil seeming to be porous and very fertile. Hay and wheat are the chief agricultural products, and as elsewhere in the region a great many cattle are raised. Wherever timber occurs it is hard wood, pine being very scarce. Near Ruthton the proportion of forest land is greater than in any part of this area, and much timber is being cut, forming a profitable industry. Lumbering becomes more and more a source of revenue as the river is ascended.

AREA DRAINED BY THE SOUTH FORK ABOVE JUNCTION WITH THE MIDDLE FORK.

This part of the drainage basin lies almost entirely on the south side of the stream—the area between the forks being too small for the formation of streams of appreciable size—and includes large areas of very mountainous country which is densely wooded. From the junction with the Middle Fork to the mouth of the Laurel Fork the basin is narrow, being shut in by the northward extension of the Holston Mountains, and excepting the land immediately bordering the stream the country is rough and rugged, with steep slopes densely forested, the valleys being extremely narrow and containing little if any cleared land, the land that is cleared being confined, so far as could be ascertained, to the narrow strip bordering the river, and therefore constituting a very small part of the whole.

Above the mouth of the Laurel Fork the mountains recede somewhat from the stream, the strip of arable land becomes wider, and cleared areas are to be found in the basins of some of the tributaries, as on Rosenbaums Creek, where the proportion of cleared land is between two-thirds and three-fourths, while of the whole area lying between the river and the road from Damascus to Holstein Mills about one-third is cleared. The area to the south of the road is entirely in forest, and the slopes are steep and rocky, the country rock being still a limestone formation.

Many sawmills are located near the headwaters of some of the small tributaries, and are engaged in cutting the hard-wood timber. There are also one or two mills along the stream, but they are cutting only a few hundred feet each day.

Widner Creek, Rush Creek, Poge Creek, Mill Creek, Grose Creek, and St. Clair Creek, all tributaries from the south, are small streams draining narrow and confined valleys and rough, mountainous, and forest-covered slopes, the small proportion of cleared land in the basin of each being confined to the narrow strip next to the stream, the country being rather inaccessible, as roads are few. There is much timber, but owing to the roughness and steepness of the mountain slopes it is exceedingly difficult to lumber it, so that up to the present time very little has been cut.

There is one notable exception to the general character of the country along the river, viz, the area known locally as the St. Clair Bottoms, situated on both sides of the South Fork between Holstein Mills and the Washington County line, extending back 1 or 2 miles on each side of the stream and embracing a large area of very beautiful grazing land, a small part only being cultivated in corn and wheat. These bottoms are broad, and from them the uplands rise very gently, the area being practically all cleared. The country rock is a limestone, a small quantity of which is burned for building purposes and to apply to the land.

Above Holstein Mills the mountains close in again and as a consequence the area is more broken and rough. Very little cleared land is to be seen either along the river or away from it until the head of the stream is reached, when the mountains again recede, leaving the broad and fertile area known as the Rye Valley, which extends from a little below Dickey Creek to and above the junction of Slemp and Cressy creeks, and is rimmed about by high and steep mountain slopes. This valley is very broad and gently rolling, and is almost all cleared and in grass. Dickey, Slemp, and Cressy creeks are small streams draining narrow valleys and areas of steep mountain slopes where the proportion of cleared land is small above the limits of the broad valley just described.

AREA BETWEEN THE SOUTH AND MIDDLE FORKS.

This area is a long and narrow strip, 5 or 6 miles in width at the widest part and about 29 miles long, measured from the headwaters of the two streams to the point of junction, and slopes from the crest of the Blue Ridge toward the southwest, the area being about equally divided between the drainage systems of the two forks.

From the junction of the streams to the slopes of the Pond Mountains the country is level or gently rolling, the hillside slopes being slight. The soil is largely a red clay quite impervious to water, though there are large areas of a light-yellow porous soil. The cleared land forms about three-fourths of the area and the wooded portions are too small and as a rule too widely separated to have much effect on the run-off.

South of Marion the large sandstone areas represented by the Pond and the Brushy mountains are all wooded and quite steep. Even where the timber has been cut away the smaller trees and underbrush have grown rapidly and cover the ground with a dense shade. Some of the slopes, however, are composed largely of a species of talus, small angular fragments of the stone comprising the mass of the uplift, covering them in places to a depth of several feet, where the growth is sparse, consisting of small bushes and straggling trees.

RAINFALL.

The annual rainfall over the basin of the South Fork is comparatively large, averaging probably between 40 and 41 inches per annum, diminishing somewhat as the stream is ascended. Over all the basin the summer rainfall seems greater than that of any other season, heavy rain storms being of frequent occurrence, causing large and rapid rises in all of the streams. Severe droughts are relatively infrequent and are soon broken. The drought of the summer and fall of 1900 was said to be the most severe in the history of the region, and it is thought that the low-water gagings made at that time represent the minimum discharges of the streams.

FORESTS.

The forest growth of the basin is mostly oak, chestnut, and pine, with some spruce, walnut, maple, hickory, beech, birch, dogwood, cherry, ash, locust, and poplar, and still smaller quantities of other woods. There are important lumbering industries, notably those near Bristol, although throughout the area numerous mills, large and small, are working up the raw material. In many places large quantities of tan bark are stripped, much of it going to the great tanneries at Bristol. The chief industry of the region, however, is cattle raising, large numbers of which are shipped annually from this section.

MINERALS.

Iron ore is found at a great many points within the basin, and is being mined at some localities, although from some cause the business seems to be languishing, most of the furnaces being out of blast. Zinc is found near Bluff City, Tenn., and gold, barytes, and fluorspar are found in small quantities at various places. There are large deposits of gypsum in the valley of Walker Creek; sandstone, granite, and dolomite occur in small areas; and limestone of excellent quality is found in abundance everywhere. Near Marion, Va., the limestone is quarried in considerable quantities and is shipped to the alkali works at Saltville, Va., where there are extensive saline deposits.

TRANSPORTATION.

The basin is traversed by the lines of the Southern Railway as far as Bristol. The Norfolk and Western Railroad extends from that point the whole length of the basin, and the Bristol and Elizabethton, the East Tennessee and Western North Carolina, the Holston Valley, and the Ohio River and Charleston Railroad afford comparatively good communication with the greater part of the area.

DISCHARGE MEASUREMENTS.

During the investigation many measurements were made of the river and its tributaries, and one gaging station was established in the basin, viz, at Bluff City, Tenn. The miscellaneous measurements made on the South Fork and also those made at the gaging station are given in the following table. The measurements made on the tributaries are given in the table on page 53.

Discharge measurements of South Fork of Holston River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 17	Bluff City, Tenn	E. W. Myers and L. V. Branch.	0.25	378
Aug. 16	do	do	0.25	329
Sept. 25	do	do	1.15	791
Nov. 8	do	do	0.90	681
Dec. 27	do	do	0.60	392
July 23	Below mouth of Middle Fork, Va	L. V. Branch	3.06	228
Oct. 3	do	E. W. Myers	3.21	190
July 28	Below mouth of Laurel Fork, Va	do	2.60	652
Oct. 3	do	do	3.39	149
July 28	Above mouth of Laurel Fork, Va	do	1.51	101
Oct. 3	do	do		48
July 27	Rye Valley, Va	do	6.96	20
Oct. 1	do	do		5

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made at Bluff City, Tenn. In making the other measurements given in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

A water power of considerable magnitude can be developed at Bluff City, Tenn., where the total available fall is between 15 and 20 feet. The only use of the power at present is by the Bluff City mill, a flouring mill having a capacity of 50 barrels per twenty-four hours, using a fall of from 5½ to 6 feet, which with one 35-inch Victor turbine develops about 30 horsepower. Formerly there was a small cotton mill located here which used about 7 feet of the fall, but that is no longer in operation. A development of power could easily be made at this place, the river being narrow, with high bluffs on each side. The railroad facilities also are good.

Above the pond of the Bluff City mill the stream is comparatively placid until just below the mouth of Dry Creek, where there is a shoal having a fall of about 8 feet in 200 yards. The bed of the river is very rough, being crossed by several ledges of rock and containing many loose bowlders. The banks are rather low, being only about 10 feet above low water.

McClellan's mill, the first mill on the river above Bluff City, is on the north bank of the stream about 50 yards above the mouth of Weaver Creek. It is a small combined sawmill, gristmill, and cabinet shop, using a small amount of power, which is obtained from an undershot wheel and a homemade tub wheel, both using a head of about 4 feet, practically all that is available. It is said that curly maple and curly birch are to be found here in considerable quantities, and that other fine cabinet woods abound.

There is one small shoal in the river between McClellan's mill and the mouth of Beidelmans Creek, but the fall is slight and the locality of no practical importance. At the time this stream was first visited, in the latter part of July, 1900, almost all of the small tributaries in this part of its course were practically dry, the largest carrying less than 0.5 second-foot. The stream itself between the points mentioned consists of a succession of still pools, seemingly quite deep, with a very low current velocity broken by short shoals where the depth of the water ranges from a few inches to about 1 foot, flowing over and among water-worn pebbles from 3 to 6 inches in diameter, with occasional rock ledges crossing, where the principal falls are found.

For some distance upstream from the mouth of Thomas Creek the hills on the north side rise rather steeply from the river's edge to a height of several hundred feet, and the valley on the south side is much narrower than those heretofore described. The country rock along the stream is a much jointed and laminated gray or black slate, striking to the northeast and dipping almost vertically. The river flows over the upturned edges of this slate, making a very rough channel, but one in which the fall is well distributed, there being little noticeable concentration at any locality.

About 200 yards below the mouth of Riddle Creek there is a small mill, known as Rosenbaum's mill, which diverts a few second-feet of water from the river by means of a low and loosely piled rock wing dam, a fall of about 5 feet being obtained through a race 150 yards long.

About 1 mile below the mouth of Fishdam Creek and just above the mouth of a small unnamed branch there is a fall of 5 feet in 300 feet, over a rough and rocky bottom, composed of angular bowlders and rock ledges. There are high and rocky bluffs on the north side of the stream, but on the south side the banks rise to a height of about 10 feet, and then a broad meadow slopes gently away. The facilities for building a good dam and a race at this point are excellent.

Just below the mouth of Fishdam Creek is one of the finest mill sites seen on the river. The current is divided by a small island, at the head of which a low loose-rock wing dam has been built, diverting a small part of the current. Another dam has been constructed about 30 yards above the foot of the island, a total fall of 9 feet being thus obtained, which is used by a small sawmill and gristmill requiring probably about 2 horsepower, which is developed by a small flutter wheel. This mill is said to have a capacity of 600 feet of lumber or 40 bushels of corn a day. Power in large quantity could very easily be obtained here, and although at present the locality is somewhat inaccessible, the graded way for the Holston Valley Railroad passes the mill and the track construction work is only a few miles distant.

Fishdam Creek enters the river at the elbow of a great bend known locally as the Horseshoe Bend. If the river be followed the distance around this bend is about 2 miles, but the distance across the narrow point of the neck is only about 200 yards. This neck is low, being at its highest point only from 40 to 50 feet above river level. From water to water across the neck there is a fall of between 25 and 30 feet, as determined by the aneroid barometer. It is stated that this neck has been leveled over and the difference in elevation in the water surfaces on the two sides determined to be 26 feet. Should it be desired to develop this power, a tunnel or an open canal could be made across the neck and all or a part of the flow easily be turned through it. On the north prong of the bend the river is rather wide, but a low dam could easily be built, and there are large areas of well-protected bottom land, lying well above high-water mark, which would afford ample room for the necessary buildings. The country rock here is a much laminated and jointed slate, not suitable for building purposes.

The next shoal on the river is just above the mouth of Sharp Creek and the Shady Ford. The river here is full of islands large and small, and the fall is heavy, being about 20 feet in a distance of less than a half mile. The water could easily be carried along the southeast bank and used where desired along the river; or by a short extension the race might be carried around a small hill and Sharp Creek be used as a tailrace. The west bank is high and rocky, with numerous bluffs, and large quantities of stone suitable for rough building operations could be obtained from it. Plenty of timber is to be found in the immediate vicinity.

Some distance above this shoal and about a half mile below the mouth of Jacobs Creek there is a shoal having a fall of 6 feet in 200 feet, with a broad bottom on the west side and a high, rocky bluff on the east side. This power, however, is not considered of importance.

From this point to the junction with the Middle Fork the river could not be closely followed, but several localities with falls of between 6 and 7 feet were noted, the first one about 3 miles below the forks. About a half mile above this fall there is a similar shoal, about 1 mile below the forks there is another, while immediately above the forks there is one having a fall of about 8 feet in 100 yards which could easily be developed, as the banks are very high and steep. The bed of the river is in solid limestone and seemingly is very rough, but the stone in the bluffs quarries well, and a considerable quantity has recently been taken out to construct the piers for the bridge of the new railroad from Abingdon to the Shady Valley, which crosses the river at this point.

About a mile above the junction with the Middle Fork is Glenn's mill, a gristmill using about 24 horsepower, which is developed by a 24-inch turbine working under a head of 7 feet. There is a loose rock wing dam which turns a small part of the water behind an island, at the lower end of which a log dam 7½ feet high has been built, from which a wooden flume 100 feet long carries the water to the mill. There is never any lack of water at this point, and high water interferes with the operation of the mill not more than four or five days in the year on an average.

Above this point there is no noticeable concentration of fall on the South Fork until the mouth of the Laurel Fork is reached, the fall, though large, being well distributed.

About a mile above the mouth of the Laurel Fork is the Rambos mill, a small gristmill using an 8-foot fall and an unknown amount of power, sufficient, however, to operate three sets of stones. The dam is of timber frames planked over and is about 3 feet high and 150 feet long. It turns a small part of the water into a race about 200 yards long. The mill is old and considerably out of repair.

From this point up to about 3 miles below the village of Friendship there are no mills on the South Fork, though several small mill sites were heard of which in the past had been occupied by small gristmills which have been washed away by the floods to which the stream is subject. About 3 miles below Friendship was the best site heard of on this part of the river and the only one visited. This is known as the Buchanan site, and it is stated that there was formerly a very good gristmill here, but nearly all vestiges of it have disappeared. The fall used was about 12 feet, though a much greater fall could be made available by the construction of a suitable dam, which could be made from 40 to 50 feet high without flooding any valuable land.

A short distance above Friendship is Vail's mill, a combined sawmill, gristmill, and planing mill, using 78 horsepower, which is developed by three Success turbines of 24, 27, and 30 inches diameter, respectively, all working under a head of 12 feet. The miller at this mill stated that he had measured the river at its lowest stage and found a flow of 8,000 cubic feet per minute. The dam is of timber frames planked on the upstream side, 12 feet high and 144 feet long, forming a pond 500 yards long. The sawmill has a capacity of 6,000 feet B. M. per day, and the gristmill a capacity of 30 barrels. The year round there is plenty of water to run all of the machinery in this mill at the same time. It is estimated that with a head of 12 feet the river at this point has a flow sufficient to develop 145 net horsepower, and that from this point to the mouth of the Laurel Fork 100 horsepower could be developed every half mile.

About 4 miles above the Vail mill is Love's mill, located just below the Smyth County line. This also is a combined sawmill, gristmill, and planing mill, and is said to use 36 horsepower, developed by a 21-inch Success turbine rated at 20 horsepower when working under a head of 9 feet, and three wooden tub wheels developing a total of about 16 horsepower. The dam is of timber frames planked on the upstream face, and is in fair condition. It is 9 feet high and 150 feet long. It backs the water a distance of three-fourths of a mile, there being little slope in the river above the dam but a considerable fall just below it. There is no race, a wooden flume 60 feet long carrying the water from the dam to the wheels.

The next mill on the river is the St. Clair roller mill, located about 2 miles below the Holstein mill, at Holstein Mills, in the area known as the St. Clair Bottoms. There is a fall of about 10 feet at this place, and the power used is developed by one 20-inch Success turbine, rated at 20 horsepower; one 35-inch Leffel wheel, Standard pattern, rated at 25 horsepower; and one 20-inch Burnham Brothers' wheel, rated at 20 horsepower; making a total of 65 horsepower when all of the machinery at the mill is in operation. The dam is a timber crib structure planked over on the upstream face, 7 feet high and 100 feet long, backing the water about 500 yards. The race is 200 yards long and gives a fall at the wheels of 10 feet. The mill is rated at 45 barrels per day and has a capacity of between 200 and 300 feet of lumber. At the lowest stages of flow there is not enough water in the river in this part of its course to operate all of the machinery in the mill at the same time.

The next mill on the stream is the Holstein mill, a combined sawmill and gristmill, evidently very old and greatly out of repair, using a fall of 12 feet and an unknown amount of power. This site is a very fine one for a small plant. The dam is of timber frames planked on the upstream face, and is very leaky. It is 12 feet high and nearly 200 feet long. There is no race, a short wooden flume leading the water directly to the wheels, two homemade affairs built on the turbine principle and yielding an unknown amount of power.

About 100 yards below this site is the site of an old woolen mill abandoned about ten years ago. Here there was a 9-foot dam about 150 feet long. At first two small turbines were used, but these required so much water that a race was dug from the dam of the upper mill, and a breast wheel 14 feet in diameter and 9 feet face was installed. This site is said to be one of the best on this part of the stream, suitable for any kind of a mill but particularly adapted for a woolen mill. The mill property includes dwelling houses, school, and church, all in good repair. The mill building has been torn down, however, and any power development would have to be made from the beginning. The valley above this mill is more hilly and is narrower than that below, which, particularly in the part known as the St. Clair Bottoms, is very broad, being 4 miles or more wide and extending back in a gentle rise to the foot of the mountains, with practically all of the land cleared.

Above this there are no mills on the stream until the Rye Valley is reached. In the upper part of that valley there is a small gristmill operating one pair of stones by a large overshot wheel and using a very small amount of power. It is only 5 miles from this mill to the head of the stream, and above it the river is too small to furnish power in appreciable quantities, although throughout the upper part of the stream, from the St. Clair Bottoms to the head of the river, the fall is very great, the stream being almost one continuous rapid. As determined by the aneroid barometer the fall between the end of the big bend immediately below the Rye Valley and the first ford below—a distance of about 1 mile—is 20 feet; between that point and the mouth of Pomer Creek it is 30 feet; between Pomer Creek and the river surface 2 miles above Holstein Mills it is 140 feet; and between the latter place and the ford below the old woolen mill—a distance of about 2½ miles—it is 150 feet. Through the St. Clair Bottoms the fall is much less, but it is still large, and there are many places where falls of from 10 to 15 feet could be utilized by the construction of dams of suitable height.

TRIBUTARIES OF SOUTH FORK OF HOLSTON RIVER BELOW JUNCTION WITH THE MIDDLE FORK.

DISCHARGE MEASUREMENTS.

During the investigation the drainage basins of all the important tributaries of the South Fork were visited and measurements were made of most of them. The results of the measurements on the tributaries below the junction with the Middle Fork are given in the following table, in order upstream:

Discharge measurements of tributaries of South Fork of Holston River below junction with the Middle Fork.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 25	Hatcher Creek	One-half mile above mouth, Tennessee.	E. W. Myers	5.92	0.34
July 20	Sinking Creek	One-half mile above Paperville, Tenn.	L. V. Branch	3.60	3.48
July 29	do	At mouth, Tennessee	E. W. Myers	4.92	11.00
Sept. 25	do	do	do	4.42	9.09
Do.	Thomas Creek	Below railroad bridge, Tennessee	do	......	2.46
July 20	Riddle Creek	At mouth, Tennessee	do	12.19	2.00
Sept. 25	do	do	do	11.13	3.00
July 20	Jonah Creek	do	L. V. Branch	11.06	4.00
Sept. 25	do	do	E. W. Myers	11.42	4.00
July 20	Fishdam Creek	do	do	5.25	5.85
Sept. 26	do	do	L. V. Branch	5.26	2.47
July 21	Sharp Creek	do	E. W. Myers	5.36	1.16
Sept. 26	do	do	do	5.33	1.19
July 21	Jacobs Creek	do	L. V. Branch	9.10	2.07
Sept. 27	do	do	E. W. Myers	......	2.00
July 21	Spring Creek	1 mile above mouth, Virginia	L. V. Branch	0.90	13.00
Sept. 27	do	do	E. W. Myers	......	10.00
July 21	Wolf Creek	Lower ford of main road up the river, Virginia.	do	2.35	7.00
July 23	do	do	L. V. Branch	2.36	7.00
Sept. 27	do	do	E. W. Myers	2.21	12.24
July 21	Denton Valley Creek.	At mouth, Virginia	L. V. Branch	5.73	6.00
Sept. 27	do	do	E. W. Myers	5.73	4.04
July 23	Fifteenmile Creek.	do	L. V. Branch	4.45	7.37
Sept. 27	do	do	E. W. Myers	4.23	10.46

NOTE.—In making the measurements recorded in the above table, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

On the following pages are given brief descriptions of the drainage basins and water powers of the principal tributary streams in this portion of the basin of the South Fork, in order upstream.

INDIAN CREEK.

The first tributary investigated was Indian Creek, which enters from the south, near Bluff City, Tenn., and has a total length of about 7 miles, following its windings. The country rock observed over the basin was a slate, brownish-black or gray in color, much laminated and broken, striking N. 70° E., and dipping sharply to the south, from 80 to 85 degrees in some cases. As the mouth of the stream was approached ledges of limestone made their appearance on the tops of the hills.

For the first 2 or 3 miles above the mouth the topography consists of low, rounded hills and broad, flattened swells, cleared to the top for the most part, and under cultivation in grain or grass, the area being about equally divided between those products. The woodland in this part of the basin amounts to only about 10 per cent of the area, but as the stream is ascended the hills are higher and more rugged, with steeper side slopes, and the proportion of cleared land is much smaller, being not more than one-third in the upper part of the basin. Over the lower part of the area the woods are composed almost entirely of hard-wood trees, but near the headwaters these give place to pine.

The fall of the stream is large, being between 450 and 500 feet, averaging between 65 and 70 feet to the mile. Very little of it is utilized, however, but there are three small mills, each using from 10 to 12 feet and operating one pair of stones by means of overshot wheels. Although these three mills use a very small amount of power, at the time the stream was first visited, in July, 1900, it was carrying too little water to operate them. The flow at the mouth was estimated to be about 1 cubic foot per second, though it could not be measured, owing to the shape of the channel. The hillside slopes vary from 15 degrees near the mouth to 50 or 60 degrees near the head of the stream.

In the first 2 or 3 miles above the mouth of the creek traces of three well-defined stream terraces were observed, the upper one being the uplands, the second one a narrow strip of level land lying from 20 to 25 feet above the present level of the stream, following its course but from 100 to 150 yards distant and sloping down very sharply to the level of the present bottom lands, which constitute the third member of the series. The descent in many cases is almost vertical.

Between the mouth of Indian Creek and the Dry Branch, the next tributary upstream, is an old mill known as Worley's mill, not now in operation, which was run by water from a big spring or sunken creek. At the time this stream or spring was visited it was carrying a quantity of water too small to operate the mill, but the discharge was estimated to be approximately 2 second-feet.

DRY CREEK.

Dry Creek, or more properly the Dry Branch, is the next tributary above Indian Creek, and like that stream it enters the river from the south. It has a total length of about 4 miles. The drainage area, which consists almost entirely of gentle swells and small grass-covered slopes or hills, is largely cleared land. At the time the stream was visited it was estimated to be carrying about 0.25 second-foot, the amount being too small to measure.

WEAVER CREEK.

Weaver Creek, the next tributary entering from the south, has a total length of between 5 and 6 miles. The part of the drainage basin lying near the river is very similar to the basins of Indian Creek and the Dry Branch just described, but as the stream is ascended the country becomes rapidly more steep and broken, on account of the rising spurs of the Holston Mountains. It is estimated that two-thirds of the total area drained by this creek is cleared land, the the greater part of it being grass covered. The discharge was estimated to be about 0.5 cubic foot per second, the quantity being too small to admit of measurement with a current meter.

HATCHER CREEK.

The next tributary is Hatcher Creek, locally known as Tow String Creek. At the time of the first visit, in July, this stream was dry, carrying no water for a mile or more above its mouth; but at the time of the second visit, September 25, although the stream discharged no water into the river it was carrying 0.34 second-foot about a half mile above its mouth. This flow, however, sank gradually into the earth within a distance of about 100 yards. The discharge was gaged just above this sink. It seems probable that this stream would begin to discharge water into the river when carrying a small quantity more than at the time of measurement. Its flood discharge is about 4 feet, and like the other streams in the region it rises and falls rapidly.

A great part of its drainage basin is in forest, and the character of the topography is much bolder than that of the areas lying farther to the west, the hills rising higher and the slopes being much steeper.

MORRILLS CREEK.

The next stream entering the river is Morrills Creek, which is about 6 miles long and drains a larger area than any of the foregoing tributaries. Near its mouth the character of the topography is similar to that of the other basins described, but as the stream is ascended the country becomes very rough and broken and the hillside slopes very rough, rocky, and steep. There is much cleared land near the river, but so far as could be ascertained there is none near the headwaters. Despite its large drainage basin, the amount of water carried by this creek at its mouth at the time it was visited was too small to admit of measurement with a current meter, but it was estimated to be about 1 cubic foot per second.

SINKING CREEK.

The next tributary—the first of importance entering from the north—is Sinking Creek, more properly known as Beidelmans Creek, for Sinking Creek is properly a small tributary of the latter stream. It has a total length of about 12 miles. The upper part of its basin, from Paperville to the head, is broad and flat, consisting of low ridges and flattened swells cultivated to the top, from 85 to 90 per cent of the area being cleared land. From Paperville toward the mouth, however, for about 2 miles the hills close in on the stream, there is considerable fall in the channel, and practically none of the land is cleared, the hillside slopes being too steep and rocky to admit of cultivation. Below this short strip the character of the country is similar to that of the upper part of the basin. The timber, which occurs largely in the 2-mile stretch just noted, is almost all hard wood, and lumbering is an important industry. So far as known there are no mines or minerals in the basin, though large deposits of iron ore are found not far distant.

There are a number of mills on Sinking Creek, all within the 2-mile stretch described, where the stream has cut its way through the Great Knobs, leaving a very rough and steep channel. The first one is about a half mile above the mouth of the creek and is known as Beidelman's mill. It is a small gristmill operating two sets of stones and using a fall of about 8 feet, the power being developed by a 14-inch turbine yielding about 10 horsepower. The dam is of wood, about 2½ feet high and 100 feet long; the race is about 100 yards long, in earth and wooden flume.

Some distance above this and a short distance below the village of Paperville is Nutty's woolen mill, which uses about 14 horsepower, developed by a 14-inch Little Giant double turbine working under a head of 13 feet, which could be increased to 16 feet. This mill operates one set of woolen machinery.

About 200 yards above Nutty's mill is Bruce's mill, which uses a fall of 35 feet on a 12-inch James Davis turbine yielding 12 horsepower and operating one set each of corn and wheat stones as well as sawmill and planing machinery. There is no dam at this mill, the water being turned directly into the race. There is plenty of water except when the mills above close down.

About 200 yards above Bruce's mill is the planing mill operated by J. T. Nutty, where about 14 horsepower is developed by a 13½-inch Burnham turbine working under a 17-foot head, which is used to operate a full line of sash, door, and blind machinery. The dam is 3½ feet high and 36 feet long, making a pond 200 feet in length. There is at all times plenty of water in the stream to develop this power, and it is stated that the fall could easily be increased to 24 feet.

A short distance above the Nutty planing mill is the sawmill operated by J. H. Maddox, where the fall is 18 feet, about 10 horsepower being developed by a homemade wheel built like a turbine. The plant consists of a small sawmill, including planer, turning lathe, and a pair of corn stones. The dam is 60 feet long and 3½ feet high, backing water to the tailrace of the mill above, a distance of about 100 yards. The race is of wood and is 96 feet long.

One hundred yards above the Maddox mill is the flouring mill of the Farmers' Milling Company, located in the village of Paperville. This is a 40-barrel roller flour mill operated by an 18-foot overshot wheel of 4½ feet face, which is said to furnish 20 horsepower. The flow of the stream at the time of the visit in July was said to be sufficient to operate the mill only about half the time, but for nine months of the year the stream furnishes water sufficient to run the mill night and day. A gaging was made of the water in this flume.

The next mill is about one-fourth of a mile above Paperville and about 2½ miles below Bristol. It is known as the Rutherford mill, and is a gristmill operating one pair of wheat stones. The dam is of wood, 8 feet high, and gives a fall of 11 feet at the mill, through a wooden race about 100 feet long. The power is developed by a 20-inch New American turbine yielding 15 horsepower. It is stated that there is generally sufficient water in the stream to operate this mill all of the time, but when visited in July the flow of the creek was insufficient to operate it more than a very small part of the time. The miller, who had known the stream many years, stated that it was at a lower stage than at any time within his recollection.

The total fall of the creek between Rutherford's mill and Nutty's woolen mill is said to be approximately 135 feet; by aneroid measurement it was determined to be 130 feet. The fall used by the several mills aggregates 121 feet, all within a distance of less than a mile.

THOMAS CREEK.

The next tributary, entering also from the north, is Thomas Creek. Its drainage basin is level to gently rolling, and is from 85 to 90 per cent cleared land, a very large proportion of which is grass covered. At the time of the July visit it was thought that the stream was carrying too little water to be measured with a current meter, but at the time of the September visit the creek was somewhat higher and was gaged a few hundred yards above its mouth. It was carrying 2.46 second-feet. The flood rise is about 5 feet. There is one small combined sawmill and gristmill on the stream, using a small amount of power, developed by an overshot wheel. Formerly there was a mill near the mouth of the creek, but it has been torn down.

RIDDLE AND JONAH CREEKS.

The next two tributaries entering from the south are known as Riddle Creek and Jonah Creek, respectively. These are two small streams of about the same size and having drainage basins of the same general character. Much of the timber has been cut from the area drained by them, and the proportion of cleared and cultivated land is about one-third of the whole. The forest growth, or more properly the undergrowth, on the remainder of the area is very sparse, owing to extensive lumbering operations. It is said that since the lumbering began the streams are much more flashy, falling much lower and rising higher and more rapidly, and that the floods are much more destructive than formerly. These streams attained their minimum stage of flow during the summer and fall of 1900. The average rise at the mouth of each is from 4 to 5 feet. Corn is the principal product of the basin, and no mines or minerals of any kind are known.

FISHDAM CREEK.

The next tributary, which enters the river from the east, at the head of the Horseshoe Bend, is Fishdam Creek. It drains an area entirely forest covered, excepting a few acres at its mouth. The immediate valley is very narrow and swampy and is covered with dense laurel thickets. The hills are steep and at the lower end of the valley are very high and mountainous. The country rock of the basin is slaty in character. The stream seems to have a large low-water flow, and is said to be less flashy than Jonah Creek or Riddle Creek, whose basins have been deforested, but active preparations are now being made to cut the timber in this area also. The Holston Valley Railroad is being graded along its course as rapidly as possible, and after that is completed the timber will rapidly disappear. Fishdam Creek, like all other streams in this section of country, reached its lowest stage during the summer and fall of 1900. During floods the rise at its mouth is about 4 feet above its average water level.

SHARP CREEK.

Sharp Creek also enters the river from the east. It is a small stream draining an inconsiderable area, the largest part of which is in forest, although there is considerable cleared land near the mouth of the stream, where the hillside slopes are gentle, ranging from 10 to 15 degrees. As the stream is ascended the hills are steeper and there is no cleared land. The cleared land in the basin amounts to about one-third of the area. On it fine vegetables and fruits can be grown, grapes thriving especially well. Much of the pine and poplar has been taken out of the forests, but the oak, beech, and chestnut remain. Considerable tan bark has been stripped, but very little has been taken out.

The slopes of the mountain sides are steep, being in some cases 60 degrees or more, and they are often covered with angular fragments of broken stone ranging in size from bits a few inches in diameter to blocks several feet across. The soil of the mountain slopes seems composed entirely of vegetable mold, which is mingled with these fragments. Near the tops of the mountains there is very little rock, the surface being covered with vegetable matter, black and moist, and the forest growth being very dense and luxuriant, composed for the most part of oak, with small quantities of chestnut, hemlock, and spruce. The stream is subject to fluctuations of about 6 feet.

The first mill on the creek is Lawson's mill, a small gristmill operating a single pair of stones by means of a small flutter wheel which yields an unknown amount of power. There is a fall of 14 feet available at this mill, but the quantity of water is very small. Moore & Graham's mill is a small sawmill near the headwaters of the creek. It uses about 14 horsepower and cuts about 500 feet of lumber a day.

Sharp Creek has a large fall and there are many sites where mills could be located.

SPRING CREEK.

The next important tributary is Spring Creek, which enters from the north, a short distance above the boundary line between Virginia and Tennessee. Its drainage basin possesses the same general characteristics as the other basins, consisting of broad, low, and rounded hills and ridges, with wide, flat spaces between, all the slopes being very gentle, and there being from 75 to 90 per cent of cleared land, the larger part of it in grass, hay, and grain, which are the chief agricultural products. In this basin limestone is the country rock and slate is seldom seen. The creek has periods of very low flow, and during floods it rises rapidly to a height of about 5 feet above its low-water level.

The first mill on the stream—Combes & Garrett's—is about a mile above the mouth. It is a gristmill containing two sets of buhrs, two stands of rolls, and a corn mill, the machinery requiring about 10 horsepower for its operation. The power is developed by a 16-foot overshot wheel with 42 inches face, which is said to yield 16 horsepower. The dam is 250 yards above the mill and is of stone, 7 feet high and about 100 feet long. By the use of a turbine 21 feet fall could be obtained at this place.

King's mill, the second mill on the stream, is 2 miles above its mouth. It is a gristmill operating three sets of buhrs driven by a 40-inch Leffel turbine working under a head of 10 feet and yielding an unknown amount of power. It is stated that 8 horsepower is sufficient for the operation of the machinery. The dam, which is at the mill, is of timber frames planked over on the upstream face, and is 10 feet high and 30 feet long, giving a pond 300 yards in length.

Hawkins's mill, the next mill above the King mill, is a sawmill having a capacity of about 2,000 feet a day, using an unascertained amount of power, which is developed by a 36-inch turbine working under a head of 12 feet. There is no race, the dam, which is of stone, 12 feet high and 35 feet long, being located at the mill. It is said that ordinarily there is sufficient water in the stream to operate this mill all of the time, but when it was visited in July the entire flow of the stream was leaking through the dam.

On the top of a hill by the roadside just before Hawkins's mill was reached three or four potholes were noticed which had been worn out in the solid limestone, the country rock over this part of the area. These holes were unmistakably due to the action of water flowing in a stream channel for a considerable period, and as they are more than 100 feet above the present level of the creek they would seem to indicate material changes in this country during very recent geologic times.

JACOBS CREEK.

The next tributary is Jacobs Creek, which flows in from the east and drains a large area of rolling country, slightly broken near the river but very rough and mountainous near the headwaters. The basin is largely wooded, in a very heavy forest growth, and probably less than 10 per cent of the land is cleared. During low water the stream falls to a very low stage, and during floods it rises about 5 feet at the mouth. So far as could be learned neither mineral nor lumber industries are carried on in this basin, nor are its waters used to operate any mills.

WOLF CREEK.

Wolf Creek, entering from the north, is the next tributary. It is about 10 miles long and drains a large area. The valley is wide and flat and is almost entirely cleared and grass covered. Limestone is the country rock, slate being seldom seen, though an occasional ledge of much jointed and laminated slate was noticed. The fall of this stream seems to differ greatly from that of other streams of the region, in that it consists of a succession of vertical plunges of from 1 to 6 feet, the intervening stretches being comparatively still and placid water. Along the upper part of the stream, near Vance's mill, the fall is very great, amounting to more than 50 feet in 1 mile, while above and below that point, where the creek flows through and between the Great Knobs, the fall is much less.

The largest fall on the creek is a few yards above its mouth, and is said to have been measured with an engineer's level and to be about 100 feet in 100 yards; the aneroid barometer, however, gave it somewhat less than that. This fall is the site of the first mill on the stream, known as the Falls mill, owned by Pitt & Nutty, of Stump, Va.

Formerly there was a fine mill here, but of late years it has been suffered to fall into disrepair. At the time it was visited in July, however, repairs were in progress, and it was stated that a roller flour mill of 40 barrels' capacity was to be installed at once. The log dam at the head of the falls is 8 feet high and 50 feet long. The race is about 100 feet long and gives a fall at the mill of 36 feet. The power is to be developed by a 12-inch double turbine, which will yield 35 horsepower under the head stated. It is claimed that this site will develop 280 horsepower the year round by using all of the fall, but there is some trouble from lack of water, which at times is held back by the mills upstream until late in the day.

Vance's mill, the next one on the creek, is about 2 miles south of Abingdon, at the upper end of the gorge referred to. It is a small sawmill and gristmill of two runs of stones, the sawmill and each pair of stones being operated by a separate overshot wheel about 16 feet in diameter. No estimate of the amount of power necessary for the operation of the machinery could be obtained. The dam is a timber structure 12 feet high and 100 feet long, and is very leaky. The race is a wooden flume about 150 feet long, giving a fall of 18 feet at the wheels. This power could be greatly increased by taking in a fall of about 6 feet just below the mill and using all of the water in two small turbines.

DENTON VALLEY CREEK.

The next tributary is Denton Valley Creek, one of the largest streams flowing into the South Fork. For the first 3 miles above its mouth there is a large proportion of cleared land in the basin, amounting to probably one-third, practically all of it grazing land. In even the cleared areas the hillside slopes are steep, ranging from 15 to 30 degrees, and show a great deal of exposed rock, everywhere a limestone. Farther upstream, however, the country becomes very rough, rugged, and mountainous, and is densely forested, with a soil that is seemingly very moist all of the time. As the creek is ascended the limestone of the lower part of the basin gives place to a slate, and near the top of the mountains the slate is replaced by a sandstone which on disintegrating becomes a fine, light-yellow to white sand. This stream falls very low and has a maximum rise of 4½ to 5 feet, rising and falling rapidly, although less rapidly than others in the immediate vicinity.

There is but one small mill on the creek, and there is no information concerning it at hand. Near the mouth of the stream are the remains of an old bloomery furnace, seemingly out of operation for many years. As no ore was heard of in the immediate basin it must have been brought from the deposits in the Shady Valley, which can be reached from the head of the stream.

FIFTEENMILE CREEK.

Fifteenmile Creek, entering the river from the north, is the largest tributary. Its drainage basin seems entirely similar, especially as to soil, country rock, and topography, to the area drained by Wolf Creek. The fall occurs in the same succession of plunges and pools as noted on the latter stream, and like it there is at the mouth a very heavy fall in a short distance, in this case amounting to between 135 and 140 feet in about 1 mile. In this part of its course the creek has cut away a deep gorge, and all of the fall could be utilized with a comparatively small expenditure of money. The flow of the stream is ample to furnish a large amount of power from the fall. A short distance back from the stream the country is flat and has the same general characteristics as noted for the limestone areas.

There is but one mill on this stream. It is at the head of the fall mentioned and is known as the Parks mill, being a combined sawmill and gristmill. The latter operates two sets of stones, one for corn and one for wheat, the power for both being furnished by one wheel, a 16-foot overshot wheel of 5-foot face. The old jig sawmill is operated by a small flutter wheel. The dam is a timber-crib structure planked on the upstream side, and is 8 feet high and 50 feet long. The race is short, partly in excavation and partly a wooden flume. It is stated that the stream never falls so low as to make it necessary to use all of the water in the operation of the mill, and according to the best information obtainable it reached its minimum stage of flow during the season of 1900.

TRIBUTARIES OF SOUTH FORK OF HOLSTON RIVER ABOVE JUNCTION WITH THE MIDDLE FORK.

DISCHARGE MEASUREMENTS.

All of the important tributaries of the South Fork below the junction were visited during the investigation, and measurements were made of most of them, the results of which are given in the following table, in order upstream:

Discharge measurements of tributaries of South Fork of Holston River above junction with the Middle Fork.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 28	Beaverdam Creek.	Damascus, Va	E. W. Myers	11.36	189.00
Oct. 3	do	do	do	12.26	32.40
July 29	Whitetop Creek.	At mouth, Virginia	do	5.47	100.00
Oct. 2	do	do	do	5.72	34.30
July 29	Atcheson Creek	Near Head of Laurel, Tenn	do	1.82	4.32
Do	Laurel Fork of Holston River.	One-half mile above Laurel Bloomery, Tenn.	do	2.06	23.00
Do	do	Near Laurel Bloomery, Tenn	do	5.12	61.00
July 28	do	One-half mile below Damascus, Va.	L. V. Branch	3.56	251.00
Oct. 3	do	do	E. W. Myers	4.61	88.14

Discharge measurements of tributaries of South Fork of Holston River above junction with the Middle Fork—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 28	Rush Creek	Ford 100 yards above mouth, Virginia.	L. V. Branch	3.63	4.20
Oct. 2	do	do	E. W. Myers		2.00
July 27	Mill Creek	One mile above mouth, Virginia.	L. V. Branch	4.32	18.00
Oct. 2	do	do	E. W. Myers	4.43	13.03
July 27	Grose Creek	At mouth, Virginia	L. V. Branch	3.88	2.00
Oct. 2	do	do		(a)	
July 27	St. Clair Creek	do	E. W. Myers	5.76	8.27
Oct. 2	do	do	do	5.94	2.00
July 27	Hogtrough Creek.	Lower ford of main road, Virginia.	do	0.87	9.00
Oct. 2	do	do	do		1.00
July 27	Pomer Creek	At mouth, Virginia	do	2.10	39.00
Oct. 1	do	do	do	2.29	5.00
July 27	Jim Scot Branch	do	do		4.12
Oct. 1	do	do	do		0.50

[a] Almost dry.

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream—the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

On the following pages are given descriptions of the drainage basins and water powers of the principal tributaries of the South Fork above the junction with the Middle Fork, in order upstream.

LAUREL FORK.

The first important tributary of the South Fork above the junction with the Middle Fork is the Laurel Fork, or Laurel Creek, as it is often called, which rises in the northwestern part of Johnson County, Tenn., and flowing in a general northerly and northwesterly direction empties into the South Fork about 4 miles above the junction with the Middle Fork, being joined in its course by two streams as large as itself, viz, Beaverdam and Whitetop creeks. It drains a rough, steep, and mountainous area containing a very small proportion of cleared land, which is confined to the small tracts lying along the stream below Damascus and to the broad meadows about the towns of Head of Laurel and Laurel Bloomery, but these are very inconsiderable in comparison with the total area drained.

Between the mouth of the creek and the first ford there is a fall of about 10 feet, and about 100 yards above this ford there is another fall of from 6 to 7 feet over rock ledges which cross the stream at right angles. Above this the average fall per mile is very large, and though it is well distributed there are a number of places where fine mill powers could be obtained by building dams; and as the banks are high and steep and the slope of the channel is great, no arable land would be flooded. As a rule the banks on the north are precipitous cliffs of limestone from 100 to 150 feet in height, while on the south side the banks are lower and in places wide bottoms spread out.

There is a fall of about 50 feet between Damascus and the mouth of Whitetop Creek, a distance of about 2 miles. The valley along this stretch is quite narrow and the banks are high, there being only two or three strips of clearing, which lie well above the limits of high water and are of small area, from three-fourths of an acre to 1 acre each. The hills rise steeply from the river, and the opportunities for building high dams are numerous.

Above the mouth of Whitetop Creek the fall of the stream is very great, being between 265 and 270 feet between that point and the first ford below the town of Laurel Bloomery, a distance of about 4½ miles, making the average fall about 60 feet to the mile. Along this portion of its course the stream falls continuously over ledges and bowlders, and there is no stretch of still or smooth water. In places the fall is greatly concentrated. The valley is very narrow, and the hills rise almost perpendicularly from the stream to heights of from 200 to 300 feet. There is much white pine and spruce throughout this section, and there seems to be absolutely no cleared land upstream from the mouth of Whitetop Creek until near Laurel Bloomery. There is only one small tributary stream in this distance, but there are many springs, and the stream gains a large amount of water from them and from seepage between the rock layers. Near Laurel Bloomery the valley widens out and contains much cleared land, practically all of it in grass. The site of the only furnace is about a half mile from the lower end of the valley. No trace of it remains, however, except remnants of the log dam and some heaps of cinders.

Between Laurel Bloomery and the gap or divide separating the waters of the Laurel Fork from those draining into the Watauga, the general appearance of the valley is very like that of the lower part of the Holston Valley, consisting, as it does, of broad, low, and gently rolling swells, almost entirely cleared and grass covered, with herds of cattle feeding over them and with the general appearance of prosperity which marked the other area. The upward slope is gradual, and the whole character of the stream seems in every way different from that of the lower part of its course.

Although power in large amounts could be obtained almost anywhere on the Laurel Fork, very little use has been made of its waters. The first power used is at the mill of A. A. M. Mock, about 1½ miles above the mouth of the stream. This is a combined sawmill, gristmill, roller mill, and flour mill. The buildings are old and greatly in need of repairs. The available fall is 10 feet, and the water is turned onto a 20-horsepower Leffel turbine, used in the operation of the flouring mill and the gristmill, while an old, homemade wheel operates the sawmill. The flour mill has a capacity of 30 barrels per day, the sawmill a capacity of less than 1,000 feet. The dam, which is of logs, is about 200 yards above the mill and is 4 feet high and 150 feet across the top.

The first power development in the valley, near Laurel Bloomery, is the pipe factory, which uses a small amount developed by a 10-foot overshot wheel with 4 feet face. This factory manufactures pipe stocks from laurel burls. About 200 yards above this is a small gristmill with only one run of stones, using a fall of 10 feet. Above this gristmill there is no utilized power until the mouth of Gentry Creek is reached, where Robinson's mill, a small gristmill of one run of stones, is located, taking water from Gentry Creek and using a fall of about 10 feet and a very small amount of power. A short distance above this mill on Gentry Creek there is a similar mill on the Laurel Fork. As far as the mouth of Atcheson Creek the fall is small and there are no mills, the creek flowing placidly along between wide and fertile bottoms.

Limestone becomes less abundant as the creek is ascended, and much gneiss, quartz rock, and sandstone make their appearance, while occasionally a thin stratum of a species of conglomerate composed of rounded and water-worn pebbles firmly cemented together and lying conformably with the limestone is to be seen.

The Laurel Fork receives two large tributaries and a number of small ones. The first tributary of importance as the stream is ascended is Beaverdam Creek, which enters just below the village of Damascus.

Beaverdam Creek.—This stream rises in the curious elevated valley between the Holston and the Iron mountains which is known and famed throughout the country as the Shady Valley. Throughout the greater part of its length the stream is inaccessible, there being no roads traversing the area, which is very rough, rugged, and mountainous, and is entirely forest covered, except for the small area of cleared land in the Shady Valley. A railroad, however, is now being built along the creek to tap the forests of the Shady Valley, and the country will soon be opened for settlement and for lumbering.

There is only one mill on the stream, and this is located a few yards above its mouth, in the village of Damascus, and is known as Wright's mill. It is a small wood-working shop and corn and chop mill, requiring about 16½ horsepower, which is developed by a 16-inch Little Giant turbine working under a head of 16 feet and using only a very small part of the water carried by the stream. The race is a wooden pipe 1,000 feet long, which follows the level of the stream. The dam is 1 foot high, barely sufficient to turn aside a small part of the water, and of course it gives no pond. At the time the stream was visited in October it was discharging 32.4 second-feet, and was said to be 6 or 8 inches above its extreme low-water mark. The flood rise at this point is about 4 feet.

Indications seem to point to the fact that the Shady Valley was at one time an old lake bed, or at any rate that still water had much to do with its present formation, since in many places timber is found buried several feet below the surface of the ground. The valley floor is rather level, though seemingly higher in the middle than at the edges. The soil is deep, rich, and moist, being very swampy in places, owing to insufficient drainage. The forest growth is very luxuriant, chiefly white pine and spruce, though some chestnut and other trees are found, some of them of great size, being 100 feet to the first limb. It is stated that the timber in the valley will average 10,000 to 12,000 feet B. M. per acre, and that some tracts will run as high as 50,000 feet per acre. In the swampy areas the soil seems to be entirely a rich, black, vegetable mold, in many places very acid and requiring the application of lime before it can be cultivated with success. In the higher parts of the valley the soil is of a light-yellowish color, with some clay, and fine crops of corn and wheat are produced. The lower part of the valley is more broken and hilly than the upper part, and the proportion of cleared land is much less, diminishing to nothing between 2 and 3 miles below the town of Shady. The Empire Lumber Company is now constructing a large sawmill in this valley. All bricks necessary for their building operations have been burned from a fair quality of brick clay found on the spot.

Whitetop Creek.—This is the next tributary of the Laurel Fork, entering that stream about 2 miles above the mouth of Beaverdam Creek. It drains a very large area, which is entirely forested, the basin being covered with high and rugged mountains having steep and rocky slopes. The fall in the creek is said to be very great and to be much concentrated in places, making wild and picturesque scenery. There are no roads traversing the basin, with the exception of one leading to Whitetop Mountain, so that the country is inaccessible unless the creek be waded. At the time of the July visit the stream was carrying 100 second-feet of water and was said to be 5 or 6 inches above its low-water level. Its extreme flood rise is between 6 and 7 feet. The timber found in the basin includes all of the varieties usually found in the high mountains, and the country rock is reported to be a limestone over the lower part of the area, giving place to metamorphic rocks as the stream is ascended. Some of the higher mountains on the borders of this basin are said to be among the most picturesque in all the mountain region, Whitetop and the views obtainable from it being particularly beautiful. This mountain is a summer resort, being a favorite place for mountain parties. The construction of the railroad up the valleys of the Laurel Fork and Beaverdam Creek will in a measure open the valley of Whitetop Creek also, and will render practicable the development of many of the water powers along its line. This will probably be the result, the power being used in the operation of small flouring mills, which will thus be enabled to find a market for their products, or in woodworking establishments, for which this section offers a very fine field, as material of the best quality exists in abundance on almost every mountain side. A beginning in this direction has been made by the establishment at Abingdon and at Laurel Bloomery of small mills for working the laurel burls into pipe shapes, from which so-called French briar pipes are manufactured. So far as could be ascertained there are no mining operations in this basin and no minerals occur in profitable quantities.

ROSENBAUMS CREEK.

Rosenbaums Creek, or, more properly, Rosenbaums Branch, is the next tributary of the South Fork. This is a small stream not more than 4 or 5 miles long, draining a narrow valley and discharging a quantity of water too small to be measured with a current meter, but which was estimated to be about 0.5 second-foot at the time of the visit in September. This is, however, not the discharge from the whole area, for as the stream was ascended the channel was found to be perfectly dry less than a mile above the mouth, though the stream was carrying an appreciable quantity of water about 1½ miles above the mouth, the entire flow sinking into the earth. So far as seen the basin consists of rather low hills, grass covered, with very steep slopes, 40 degrees in some cases. The proportion of cleared land is large, being between two-thirds and three-fourths of the area, and is confined to a strip lying along both sides of the creek. Much of the area—probably more than one-half—is in grass, the remainder being about equally divided between corn and wheat. The country rock seems invariably a limestone, and the soil is light and porous. A small amount of timber is being cut on the hills rimming the basin, being worked by a number of small mills on the spot.

WIDNER CREEK.

Widner Creek joins the South Fork about 2 miles above the mouth of Rosenbaums Creek, and though the area drained by it seems to be slightly larger than that drained by the latter creek, and a larger proportion of the basin is said to be forested, the discharge was very much less, being inappreciable at the mouth, the only place where the stream could be seen.

RUSH CREEK.

Rush Creek, the next tributary, enters the South Fork about 2 miles south of the village of Friendship, and is a slightly larger stream than either of the last two described. The area drained is very rough and mountainous, and is about two-thirds forest covered. At the time it was visited, on October 2, it was carrying 2 second-feet, and was said to be at its lowest known stage. Its flood stage is about 3 feet higher.

MILL CREEK.

Mill Creek, the largest and most important tributary entering the South Fork along this part of its course, was gaged about a mile above its mouth, the only place where the stream could be reached, and on July 27 was carrying 18 second-feet and on the 2d of October 13.03 second-feet. The drainage basin is inaccessible and was not visited. Residents of the locality state that with the exception of a narrow strip along the creek not far from the river the basin is very rough, rugged, and steep, and is entirely forest covered. Much less than one-third of the total area is cleared land. There are a number of large springs in the basin. The stream was stated to be at its extreme low-water flow at the time of the October visit, when it was carrying 13.03 second-feet. The average flood rise is about 4 feet, although in some cases it has been as great as 5 and 6 feet.

GROSE CREEK.

Grose Creek is a small branch which was carrying 2 second-feet on July 27, but was almost dry at the time of the October visit. Its drainage basin seems to differ in no way from those of the streams entering below it.

ST. CLAIR CREEK.

St. Clair Creek drains perhaps a larger proportion of cleared land than any other stream in this vicinity, all the land along it being cleared to the foot of the mountains, but probably four-fifths of the entire basin is in forest. This stream was measured near its mouth at time of extreme low water, on October 2, and was carrying 2 second-feet. The rise during floods is about 4 feet.

Considering as a whole the area drained by Widner, Rush, Grose, and St. Clair creeks, it is very rough and mountainous, with steep, forested slopes, the small proportion of arable land, which amounts to less than one-fifth of the area, being confined to narrow strips bordering the creeks and immediately along the river.

WEDSTONE CREEK.

Wedstone Creek enters the river from the south, at Holstein Mills, and at the time it was visited it was carrying a quantity of water too small to even be estimated. Its extreme flood height is about 3 feet above its low-water stage. Its drainage area is largely cleared land, the forested portion being less than that of any of the other basins mentioned and estimated to be about one-third.

HOGTROUGH CREEK.

Hogtrough Creek, the next tributary above, was also too small to measure at the time of the September visit, carrying about 0.5 second-foot (estimated), which is probably the minimum flow. The flood height is about 3 feet. The area drained is for the most part rough and steep, and the proportion of cleared land is very small, being confined entirely, so far as could be ascertained, to the first 2½ or 3 miles above its mouth and to tracts lying within 200 or 300 yards of the stream.

There are two small mills on the creek, the first one about 100 yards above its mouth, being a small sawmill and gristmill known as Pierce's mill. The power is obtained from a 16-foot overshot wheel with 4 feet face. The mill operates only one pair of stones, grinding for toll only, and saws an extremely small amount of lumber. About a mile above the mouth of the creek is a small mill operating one pair of stones by a 16-foot overshot wheel, but the name of the owner was not ascertained, nor any data regarding the power developed.

POMER CREEK.

Pomer Creek is the largest tributary to the South Fork in this part of its course. It drains an area rougher and steeper than any of those yet described, and one containing a smaller proportion of cleared land. The cleared area is confined to a narrow strip along the stream close to its mouth. There are no mills on the creek, so far as could be ascertained, though about a mile above its mouth there are evidences of a mill, which was probably washed away by one of the freshets to which the stream is subject. This creek reached its minimum flow in the fall of 1900. It was measured on October 1, when the discharge was 5 second-feet. The flood rise is about 4 feet. The amount of water carried during floods is very great.

This was the last tributary investigated, as the river was not followed much above the Rye Valley, and was too small at this point to be of value for water-power purposes. There is but little scenery worthy the name to be found over the larger part of this area, most of the country presenting a very quiet, pastoral type of beauty.

MIDDLE FORK OF HOLSTON RIVER.

PHYSICAL FEATURES.

The Middle Fork rises a little to the south of the village of Old Mount Airy, Va., on the western slope of the Blue Ridge, in the valley between Walker Mountain on the north and the Brushy Mountains on the south, and flows in a direction generally parallel to the course of the South Fork until a few miles above the junction, where it turns to the southwest. Below the junction the stream continues its general southwesterly course, and after being joined by the Watauga it unites with the North Fork of Holston River, near the town of Kingsport, Tenn., forming Holston River, which is in turn joined by the Nolichucky and the French Broad and finally unites its waters with those of the Little Tennessee, forming a system which drains southeastern Virginia, western North Carolina (excepting a small portion the waters from which flow into the New river system), eastern Tennessee, northern Georgia, and northern Alabama. That part of the area lying in the basin of the South Fork is mapped on the Roan Mountain, Bristol, Abingdon, and Wytheville atlas sheets of the Geological Survey. The area drained by the Middle Fork lies mostly to the north of the river, the distance from the summit of the ridge dividing its watershed from that of the South Fork to the stream being too small to admit of the formation of streams of considerable size. The general character of the country is similar to that of the area drained by the South Fork below the junction, the topography consisting of small and rounded hills and ridges, grass covered to the top, with very gentle slopes and with low divides between the small creek watersheds. By far the larger part of the area is cleared land, the woodland amounting to probably less than 10 per cent for that part of the basin lying between the junction and the mouth of Bear Creek. Above that point the valley becomes very narrow, being constricted between the slopes of the two peaks forming the Brushy Mountains, which are in a large measure wooded. Throughout the remainder of the basin the wooded areas are mostly in the form of small groves or tracts of a few acres. The soil is seemingly very fertile and is light and porous, though some areas of clay were found. Limestone is the country rock, and the bed of the river is also in that stone. The area drained by the Middle Fork constitutes the finest and most prosperous farming and stock-raising country seen during the whole investigation, and the lands are held at a high valuation.

DISCHARGE MEASUREMENTS.

During the investigation a number of measurements were made of the flow of this stream and of its principal tributaries. The measurements made on the Middle Fork are given in the following table, those made on its tributaries are given in the table on page 73.

Discharge measurements of Middle Fork of Holston River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 25	Sevenmile Ford, Va	L. V. Branch	13.00	71.23
Do	Above mouth of Bear Creek, Virginia	do	6.23	18.00
Oct. 1	do	do	7.69	11.00
July 24	Five miles above mouth, Virginia	E. W. Myers	5.96	172.00
Sept. 28	do	do	6.21	100.00

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

WATER POWERS.

For 100 yards above the junction with the South Fork there is a fall of about 8 feet in 100 yards, as near as could be ascertained, over a very rough and rocky bed formed by ledges of limestone crossing the river at right angles. High and steep bluffs rise from the water's edge on both sides of the stream, and from them large quantities of limestone could be quarried. A railroad crosses the stream just below the shoals, and would afford ample transportation facilities. This locality would repay an investigation by anyone desiring power in this section.

About 2½ miles above the mouth of the stream there is a fall known as Big Shoals, where the river is divided by several islands, the largest of which is about an eighth of a mile long. In one-fourth of a mile, as near as could be estimated, there is a fall of 10 feet, determined by hand level and aneroid, and near the head of the shoals there is a fall of about 4 feet in a distance of 100 feet, and an abrupt descent of about 3 feet at the foot over a rock ledge crossing the stream at right angles. On the south side of the river broad bottoms extend the length of the shoals, but on the north side the banks are high and bluffy. The country rock close to the river seems to be slate of two varieties, one hard and black, the other soft and either yellow or gray. Limestone occurs in small quantities close to the stream, but it forms the predominating rock of the uplands.

From the mouth of Hogthief Creek to De Busk's mill the river is a placid stream, with very little fall. The rock is a limestone which quarries well, and almost all of the country, which is very rolling, seems to be cleared. At De Busk's mill there is no race, a wooden flume taking the water from the forebay to the wheels. The dam is a timber structure planked on the upstream face, 10 feet high and 168 feet long, backing the water about 2 miles. The mill is a sawmill, but it also contains wood-working machinery. It is operated by a 36-inch turbine rated at 30 horsepower under 9½ feet head, and has a capacity of 5,000 feet of lumber per day. At this site there is also a wheat mill with a capacity of 30 barrels per day, consisting of three double stands of rolls operated by a 20-inch Success turbine rated at 25 horsepower. The corn and feed mill is operated by a homemade wheel yielding about 4 horsepower. Sometimes during very dry seasons when all of the machinery of the mill is in operation at the same time the whole flow of the stream is required, as the dam is somewhat leaky, and at times the pond has been drawn down 1 foot during a day's run.

Above the De Busk mill and as far up the stream as Chilhowie there is very little fall in the river, and what there is is very well distributed, there being no noticeable concentration at any place. There are localities, however, where dams from 10 to 15 feet high could be built, but in every case the fall obtained would be that due to the dam, and the flooding of valuable lands above would prohibit the construction. The bottoms are very broad and lie only a few feet above the level of the river. The river receives practically no drainage throughout this part of its course, one stream only, Huttons Branch, being large enough to gage. The country rock is a limestone, and the land is practically all cleared and is given over to stock raising and to grain.

Above Chilhowie and as far as Sevenmile Ford there is no concentration of fall in the stream, and the country preserves the same general character, except that the bottoms begin to grow narrower and the hills to close in on the river and to rise higher and more sharply, the country presenting a much more broken appearance. The area is not so largely cleared, there being probably 25 per cent of woodland in this section. The stream has an extreme rise of 12 feet in this part of its course. At present there is no mineral industry hereabouts, though several years ago much baryta was mined, but practically all has been taken out that can be worked at a profit.

Glenn's mill is the first mill on the river above the De Busk mill. It is just above the mouth of Byars Creek, and is a combined gristmill and sawmill having a capacity of 40 barrels of flour per twenty-four hours, and, with three choppers, requiring about 46 horsepower. The total power development here is 64 horsepower. The wheels are homemade, center discharge, built on the turbine plan, and of 20, 16, 10, and 6 horsepower, respectively. The sawmill contains one sash saw requiring for its operation about 12 horsepower. The dam is of timber frames planked over, and is 11½ feet high and 120 feet long, giving a working head of 11 feet at the mill and backing water about three-fourths of a mile. It is stated that there is always sufficient water to operate all of the machinery in this mill at the same time, though the dam is somewhat leaky.

The next power on the stream is about one-fourth of a mile below the town of Marion and is owned by Messrs. Look & Lincoln, who state that a fall of 10 feet can be obtained by building a dam of that height, and that no arable land would be flooded.

Look & Lincoln's mill, the next power above, is in the lower end of the town of Marion. Wagons, plow handles, and wagon materials are manufactured.. There are two dams, the upper one of stone for half its length and of wood for the remainder, 9½ feet high and 110 feet long, the water being turned directly into a 33-inch Success turbine developing about 30 horsepower. It is estimated that with this fall from 40 to 45 horsepower can be obtained the year round. Just below this dam the river makes a very abrupt bend, and about 150 yards below the upper dam, if the course of the river be followed, or 40 yards in a straight line, is the lower dam, belonging to the same firm. This dam is 8 feet high and 100 feet long, made of timber frames planked over, and backs the water to the foot of the upper dam. The water is led direct to a 36-inch turbine yielding about 20 horsepower, which is used occasionally to operate two sets of corn stones and a turning lathe. A steam engine of 100 horsepower is also used in the wagon-material department. The whole mill has a capacity of about 300 farm wagons annually and about 2,000 pairs of plow handles.

In the upper end of the town of Marion is Hull & Staley's mill, which has a capacity of 75 barrels of flour per day. The dam is one-fourth of a mile above the mill, and is of timber frames planked over.

It is 12 feet high and gives a head of 20 feet at the mill. There are two turbines, one a 30½-inch Leffel developing 32 horsepower, the other a 24-inch Success wheel developing 18 horsepower, and it is said that in seasons of low water the entire flow of the stream is necessary to operate the larger wheel.

About 3 miles above Marion is the Mount Carmel mill, a flouring mill with a capacity of 50 barrels per day, using about 32 horsepower, which is developed by two 30½-inch Leffel turbines working under a head of 9 feet. There is no race, the mill being built at the dam, which is new, of timber frames planked over, 9 feet high and 125 feet long, backing the water about 400 yards. The miller estimates that in the driest seasons there is in the stream only water sufficient to develop 16 horsepower with this head. He also stated that a portion of the water carried by the stream sinks into its bed between this mill and the town of Marion, but no evidence of this was seen.

There are no other mills or mill sites between the Mount Carmel mill and the mouth of Bear Creek, although the fall is considerable, and from the configuration of the country it seems probable that at a number of localities small amounts of power could be developed. The north side of the river is very steep and bluffy, and on the south side the bottoms are higher above the river level than at any other place along the stream. Considerable limestone has been quarried in this vicinity, the greater part of it going to the alkali works at Saltville, Va.

TRIBUTARIES OF MIDDLE FORK OF HOLSTON RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the important tributaries of the Middle Fork:

Discharge measurements of tributaries of Middle Fork of Holston River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 24	Hogthief Creek..	One-half mile above mouth, Virginia.	L. V. Branch	5.00	5.00
Sept. 29	.....do	.....do	E. W. Myers	....	5.00
Do ..	Cedar Creek.....	At mouth, Virginia	.....do	....	3.42
Do ..	Halls Creek......	.....do	.....do	1.73	17.36
July 23	Huttons Branch.	.....do	L. V. Branch	4.45	5.00
Sept. 29	.....do	.....do	E. W. Myers	4.43	5.00
July 25	Walker Creek...	50 yards above mouth, Virginia ..	.....do	4.90	3.00
Sept. 29	.....do	.... do	.....do	4.89	9.00
July 25	Byars Creek.....	At mouth, Virginia	L. V. Branch	1.52	4.00
Sept. 29	.....do	.....do	E. W. Myers	1.58	2.24
July 25	Hungry Mother Creek.	Ford of main road from Marion, Va.	L. V. Branch	1.18	2.45
Oct. 1	.....do	.....do	E. W. Myers	1.17	2.38
July 25	Staleys Creek ...	Marion, Va	L. V. Branch	9.28	14.32
Do ..	Bear Creek	At mouth, Virginia	.....do	6.99	2.01
Oct. 1	.....do	.....do	E. W. Myers	6.90	3.00

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Descriptions of the drainage basins and water powers of these tributary streams are given on the following pages.

HOGTHIEF CREEK.

The first tributary of the Middle Fork of sufficient importance to deserve mention is Hogthief or Sevenmile Creek, which enters the river from the north, at Moab, Va., and has a reported length of about 7 miles, although as measured on the map it is only about 4 miles long. The greater part of its drainage basin is cleared, the woodland amounting to probably not more than 5 per cent of the area. About half of the cleared land is in pasture, the remainder being about equally divided between corn and wheat. The whole basin is either flat or gently rolling, though it contains a few small hills, some of which are wooded to the top, but the hillside slopes are all very gentle. Limestone is the country rock of the area. When the stream was visited (first on July 24 and again on September 29) it was, according to all obtainable information, lower than ever before known. On both occasions it was discharging 5 second-feet. It is stated that the maximum rise is about 4 feet. This stream is now much more flashy in nature than it was several years ago, due no doubt to the deforestation of its headwaters which has taken place within the last few years. Not only do the floods rise with greater rapidity and to a greater height than formerly, but during the dry seasons the creek falls to much lower stages, despite the fact that it is fed by many large springs.

The first mill on the stream is Kendrick's mill, located about 100 yards above its mouth. This is a gristmill of two runs of stones, operated by a turbine 12 inches in diameter, which develops 20 horsepower under a head of 27 feet, though it is probable that 10 horsepower will operate all of the machinery in the mill. The dam is about 100 feet above the mill and is about 5 feet high and 25 feet long, built of timber frames planked over, and gives a very small pond. According to the statement of the miller the stream was never too low to run the mill until 1899, but it has been so, except at intervals, since that time, and he attributes it to the cutting away of the timber from the headwaters.

CEDAR CREEK.

The next tributary of the Middle Fork is Cedar Creek, which enters the river from the north, about 3 miles above the mouth of Hogthief Creek, which it seems to resemble in every respect. Practically all of the area drained by Cedar Creek is cleared land, which is used almost exclusively for grazing purposes. The meadows are broad and fertile, and the grass-covered uplands are nearly level. There are a few small hills, but they have very gentle slopes. It is possible that this stream may fall about one-tenth of a foot lower than its stage at the time it was visited (September 29), when it was discharging 3.42 second-feet. Its maximum rise is about 3 feet above its low-water mark.

HALLS CREEK.

Halls Creek, which enters the river a short distance below De Busk's mill, is a slightly larger stream than either Hogthief Creek or Cedar Creek, but the distinguishing characteristics of its drainage basin seem similar in every respect to those noted for the other creeks. It falls between 2 and 3 inches below its level at the time it was visited (September 29), when it was discharging 17.36 second-feet. During floods it rises between 3 and 4 feet.

HUTTONS BRANCH.

The next tributary is Huttons Branch, locally and more properly known as Huttons Creek. This stream rises on the southern slopes of Walker Mountain and drains a very small area of wooded land. The rest of the basin is cleared and is used almost exclusively for grazing, being quite level, with very broad bottoms and small, gentle hills. This stream was visited on July 23 and on September 29, and at both times was carrying 5 second-feet. Its high-water rise is 3 feet. There is one mill on the creek, operating a single pair of stones by means of a 16-foot overshot wheel and using a very small amount of power. The creek forks just below the site of the mill, the forks being at an angle of nearly 180 degrees, and the water from both branches is brought to the mill through a long wooden flume.

CHILHOWIE BRANCH AND CARLOCKS CREEK.

These are the only other streams in this section carrying an appreciable amount of water, and their discharge was much too small to admit of measurement.

WALKER CREEK.

Walker Creek, draining the southern slopes of Walker Mountain, is the next tributary of the Middle Fork. The upper part of its basin is rough and steep and is practically all in woodland, but immediately along the forks there are considerable areas of cleared land, and below them practically all of the basin is cleared. Over this lower part the topography is similar to that noted for the streams lying farther down in the drainage basin of the main stream, except that the hillside slopes are somewhat steeper and the hills a little less rounded. The creek is said to have attained its minimum stage of flow during the summer and fall of 1900. Its flood rise is about 4 feet. There are very valuable and extensive deposits of gypsum in this basin, but they have been very little or not at all worked.

BYARS CREEK.

This creek enters the Middle Fork from the south, about 4 miles below the town of Marion, Va., and is the first important tributary rising in the area between the Middle and South forks. Considerable of the land in its basin is cleared and under cultivation or in grass. It is rather smooth and level, all of the slopes being gentle. Limestone is the country rock, and it has been quarried in large amounts for use in the alkali works at Saltville. During floods the creek rises about 3 feet at its mouth.

HUNGRY MOTHER CREEK.

The next tributary is Hungry Mother Creek, on the southern slopes of Walker Mountain. The upper part of its basin is a very rough and rugged country of extremely steep slopes, containing a small proportion of cleared land. In the lower part of the basin the country is much more broken than that of the basin of any tributary of the Middle Fork yet described, the hills rising sharply from the stream to considerable heights, and the uplands, which downstream were a plain, consisting of small and rugged hills, seemingly not more than half cleared. In this part of its course the valley of the creek is very narrow. Most of the cleared land is in grass, the remainder being cultivated in wheat; and although much of the area near the mouth is still in woodland, it seems probable that these areas are too small to have very great effect on the run-off. The soil seems shallow, and there is much exposed rock over the basin, all of it seemingly a limestone formation. The floods on this stream are violent, the creek rising 5 feet in a very short time, but the periods of high water are of short duration, owing to the great slope of the stream channel and the steepness of the hillsides over the basin.

STALEYS CREEK.

Staleys Creek, entering the river from the south, within the limits of the town of Marion, Va., is the next tributary. The valley of this stream so far as seen was very largely cleared, probably 50 per cent or more. The lower part of the basin is rolling and grass covered, but the upper part consists of the northern and eastern slopes of the Pond and the Brushy mountains, and is rough, broken, and mountainous, the slopes being very steep and forest covered. The lower part of the basin is in a limestone formation, but the slopes of the mountains are of sandstone. About 4 miles from Marion, in the valley of this stream, is an iron mine owned by Mr. J. L. Woodruff, of Marion, from which about 100 tons of ore are shipped daily to the furnace at Pulaski, Tenn.

The fall of the stream is considerable and it is more largely used for power purposes than any stream of its size in the region. The first fall is known as the Old Foundry site. A fall of 17 feet can be obtained at this place, yielding about 20 horsepower. The site is now unoccupied, but a small wagon factory is to be built at an early date.

About one-fourth of a mile above the Old Foundry site and practically one-fourth of a mile above the mouth of the creek is Seaver's planing mill, where the fall is 18 feet, and it is said that 18 horsepower is developed by one 18-inch Success turbine. The race is a plank flume 1,400 feet long, and there is practically no dam, only a slight obstruction, just sufficient to turn aside the water of the creek. The mill contains wood-working machinery and a gristmill, and it is said that the stream does not at all times furnish power sufficient to develop the horsepower stated, occasionally falling so low as to yield only about 9 horsepower with 18-foot fall.

Atkins Brothers' mill is 4 miles above the Seaver mill and manufactures spokes, hubs, pick handles, etc., and saws walnut timber for export. It uses about 18 horsepower, developed by an 18-inch Success turbine working under a head of 18 feet. There is a very slight dam, barely sufficient to turn the water aside. The water is led to the mill by a plank flume 200 feet long. This is the last mill on the creek.

BEAR CREEK.

Bear Creek, which enters the river from the north about 5 miles above Marion, Va., drains a part of the southern slopes of Walker Mountain and the northern slopes of the Brushy Mountains. The whole area is extremely rough and mountainous. Probably less than one-third of it is cleared land, the cleared areas being confined to the comparatively level land immediately along the stream and to some of the lower and more gentle slopes. The stream probably never falls lower than the point reached during July and August, 1900, when it was carrying about 2 second-feet. During floods it rises about 4 feet at the mouth. Some timber has been cut in the valley, and considerable quantities of tan bark are stripped and hauled to the railroad at Marion. There are no mills on this stream.

WATAUGA RIVER.

PHYSICAL FEATURES.

Watauga River rises on the northern and eastern slopes of Grandfather Mountain, on the southern boundary of Watauga County, N. C., and after flowing about 6 miles in a northeasterly direction is joined by Boone Fork, a stream which rises on the eastern slope of Grandfather Mountain and flows first due east about 4 miles and then to the north about 4 miles, or to its junction with the Watauga. At the junction the river changes its course to the northwest, and with many bends, rapids, and falls flows through Watauga County, N. C., and Johnson and Carter counties, Tenn., uniting its waters with those of the South Fork of Holston River about 9 miles northwest of Johnson City. In its course it is joined by many tributaries. It drains an extensive area, a large part of which lies in the high mountains. The basin to the west of Carter, Tenn., was not examined, being well out of the mountains and of the same general character as the valley of Holston River already described. For convenience the basin has been divided into three parts, which are differentiated by very well marked physical characteristics. The divisions are: (1) The area lying to the west of the Iron Mountains on the north side of the river; (2) the area lying to the east of the Iron Mountains; and (3) the area lying to the west of the Iron Mountains on the south side of the river.

AREA LYING TO THE WEST OF THE IRON MOUNTAINS ON THE SOUTH SIDE OF THE RIVER.

This portion of the drainage basin of Watauga River comprises the areas drained by Gap Creek, Powder Branch, Buffalo Creek, Sinking Creek, and Brush Creek and is some distance from the mountains. As a consequence it is much less rugged than the country farther to the east, is better adapted to agriculture, and a great part of the land is cleared, hay being the principal product, though much corn and wheat are grown. Most of the area drained by these streams is either level or very gently rolling, and over the greater part of it probably about 90 per cent of the land is cleared, the woodland being confined to the tops of some of the higher hills and to small and isolated areas on the lower but less fertile tracts. Of the total area drained by these streams probably more than 75 per cent is cleared. The soil is deep and fertile and the country rock is without exception a limestone.

One of the peculiar features of this area is the large number of small closed drainage basins, or sinks, which have been noted in other watersheds of the region and which here occur in the nearly level uplands dividing the basins of the various small creeks. These sinks are particularly noticeable for their size and number near Milligan, Tenn., at which place occur the largest seen during the whole investigation, one of them covering an area estimated at 10 acres and having a large pool of water in its bottom. This locality is the only one, however, over the whole area drained by Watauga River in which these basins occur.

AREA LYING TO THE WEST OF THE IRON MOUNTAINS ON THE NORTH SIDE OF THE RIVER.

This portion of the basin includes the valley of Lick Creek, the areas drained by several small branches, the large valley drained by Stony Creek, and a part of the high and rugged area covered by the Holston Mountains. The latter, however, from its character more properly belongs to the area lying to the east of the Iron Mountains.

For perhaps a half mile or a little more to the north of the river, near Carter, the country is very hilly and rough, with steep slopes, and is largely wooded. It changes gradually as the level of the uplands is reached and becomes gently rolling, being composed of large and broad swells or ridges and low, flattened hills rising from 25 to 30 feet above the level of the valleys between them, the valleys being generally broad areas of level land. The hillside slopes are very gentle, ranging from 5 to 10 degrees. About 75 per cent of the area appears to be cleared, about half of the cleared land being grass covered.

Limestone is the country rock, as on the south side of the river, but very little is seen exposed. The soil is deep and fertile, that in the immediate valleys of the creeks being largely alluvial, while on the uplands it is gray or yellow in color and loose and porous in character.

The forest growth, which is pine, oak, and chestnut, is in small areas, which as a rule are too widely separated to have much effect on the run-off.

The country immediately along the river from Carter to the town of Watauga Valley is much broken by a number of large hills, which are much steeper than those heretofore observed, but just above the latter place these recede from the river, leaving the general appearance of the topography similar to that noted on the south side of the stream, though a little more broken and rough. The hills are the outliers of the Holston Mountains, and are covered with a dense forest growth.

Near Elizabethton the bottom lands are very broad and fertile, extending up the river as far as the mouth of Stony Creek. The valley of the latter stream is of considerable width. Immediately along the creek and on the first bench or terrace the cleared land forms a large portion of the area, but with this exception the basin is in forest. The cleared land is said to amount to from 10 to 12½ per cent of the whole, this being all that is fit for cultivation, on account of the steepness of the slopes, the mountains rising very sharply from the valleys. They all are heavily timbered, little lumbering having been done in this area.

AREA LYING TO THE EAST OF THE IRON MOUNTAINS.

This part of the drainage basin of Watauga River differs very greatly from the areas just described, being rough, rugged, steep, and mountainous, containing a very small proportion of cleared and cultivated or cultivable land, being largely covered with the original forest growth, which is rank, dense, and luxuriant.

As the river is ascended the limestone, which was the country rock over the areas just described, gives place to slates, shales, schists, and sandstones, and these in turn to granites and gneisses, which form the country rocks over all of the basin in North Carolina. Away from the river the land seems to be about one-fourth cleared, but instead of the deep and fertile surface covering seen before the soil is shallow and in many places is full of rock fragments, often angular, sometimes rounded as if waterworn, and in many places a stratum of these fragments 2 or 3 feet beneath the surface is seen exposed in the banks by the roadsides.

Toward the North Carolina line the amount of cleared land diminishes greatly, the mountains rising too steeply from the water's edge to admit of clearing. As the river is ascended the valley narrows and the mountains rise to greater heights, often showing precipitous walls of bare rock several hundred feet high, forming a chasm known as the gorge of the Watauga. An occasional small clearing may be found on the slopes back from the river, where the country is less rugged, and on these settlers try to wring a scanty subsistence from the stony soil; but as a rule the mountains are forested to the top, though occasionally an undue amount of exposed rock on the slopes renders the growth sparse and stunted.

Within the gorge of the Watauga there is no room for a road and barely space enough for the stream. The channel is very rough and broken by many rapids and sudden falls, and the water rushes along with great velocity. In the 8 miles through which the gorge may be said to extend the average fall is about 65 feet to the mile, and in many places it is much more concentrated, one notable locality being near the State line, where there is a straight plunge of 10 or 12 feet, known as the Falls of the Watauga.

Upstream from the gorge the mountains rise to less heights, the valley broadens slightly, and the uplands back from the river are suitable for agriculture on a small scale. They are partially cleared and cultivated in grass or grain in the places where the hillside slopes are not greater than 20 or 30 degrees. The hills do not recede far enough to permit the formation of bottoms until the broad strip of level land known as Valle Cruces is reached. A short distance above this the gorge is redeveloped, though in a lesser degree, and there is very little cleared land directly along the river until Shulls Mill is reached. There are small areas of cleared land up some of the tributaries, however, also along the river between Shulls Mill and Foscoe, so that it is estimated that of the total area drained by the river above the North Carolina line about one-third is cleared land; but after an inspection of the basin this estimate seems too great. Above Shulls Mill the Watauga has a length of from 5 to 6 miles, measured in a straight line, and drains an area of which a large part is well suited to agriculture, being in the form of broad and fertile bottoms and terrace lands lying close to the stream. About 4 miles above the mouth of the Boone Fork, however, the slopes of Grandfather Mountain on the north and of Hanging Rock on the south close in on the river and the amount of arable land becomes very small, the cleared land being about one-fourth or one-fifth of the whole area above the junction of the Boone Fork. The soil of the bottoms is deep and fertile, being largely a black alluvium, but that of the hillsides is often shallow and full of angular fragments of broken stone, and is not very productive.

The portion of the basin in North Carolina lies in Watauga County, which occupies the entire breadth of the very elevated mountain plateau between the Blue Ridge and the Unaka mountains. It is traversed in a northerly direction by two massive cross chains connecting these two great ranges, viz, the Rich Mountains and the chain of which Grandfather Mountain may be taken as the starting point and Hanging Rock and the Beech Mountains as the prominent peaks, the basin of the Watauga lying to the west of the Rich Mountains. The surface of the whole country is very rough and rugged and has an average elevation of about 5,000 feet above sea level. The stream valleys are as a rule very narrow, but at intervals there are considerable stretches of bottom lands. The soil is generally a stiff gray or yellow loam, producing grains and grasses in abundance. Cattle raising is an important industry. Along the headwaters of the stream there is much alluvial soil in the creek bottoms and a great deal of vegetable mold on the mountain slopes, while on Banner Elk Creek and Elk Creek the bottoms assume the form of peaty bogs, which are very deep and retain the water draining into them from the mountain slopes for a long time, feeding it out to the streams gradually.

SCENERY.

All of the area drained by the Watauga in North Carolina lies in the high mountains, and the scenery is wild and picturesque, the exact opposite of that along the lower part of the stream or on the Holston, which is quiet and pastoral. Many beautiful mountain views are to be obtained, with quick-changing cloud shadows and with wisps of filmy clouds clinging about the summits, but the valleys are so narrow and so tortuous that it is seldom a view can be obtained from a sufficient distance to give its full beauty, although there are places near the gaps and on the divides where may be seen views approaching in grandeur any that the mountains afford.

The rugged beauty of the whole area finds its culmination in the massive bulk of Grandfather Mountain, which rises to a height of 5,964 feet, far above any peak in the vicinity, and is probably the most massive, wild, and rugged of the peaks of the Southern Appalachians. Though by no means the highest peak in the range, it so towers above its surroundings that one of the most extensive views in North Carolina can be obtained from its summit. From certain directions and in clear weather the summit of this mountain is seen to form the profile of an old man—hence the name—but this is seldom visible, for this grandfather of mountains keeps his face almost perpetually veiled in the clouds.

RAINFALL.

Like all other drainage basins throughout this region, the basin of the Watauga is subject to a very heavy annual rainfall, being greater near the headwaters, where Grandfather Mountain causes an almost constant precipitation. This rainfall at times comes in the form of violent rain storms, but these are infrequent, the precipitation being well distributed throughout the year, though the summer rainfall is the greatest in amount. At times the heavy rains are long continued, lasting a week or more, and the streams rise to great heights and do a vast amount of damage. It is said that the greatest flood known in this section of the country occurred in 1867, when there was a week of heavy rainfall, followed by a violent rain storm lasting twenty-four hours and seemingly extending over the whole basin. At Butler the river rose 18 feet above its low-water mark, washing away several houses and barns and totally destroying a great many acres of valuable bottom lands lying immediately along the river. Similar floods are reported to have occurred in the valley of Roan Creek in 1861 and in 1870. Droughts are infrequent, and as a rule are neither severe nor long continued, the drought of 1900 being the most severe within the memory of the inhabitants of the basin.

SPRINGS.

A marked feature of the region is the great number of springs, the discharge of which ranges from less than a gallon a minute up, several being of very large size. One of the larger springs is in the village of Allentown, Tenn. The spring basin is nearly 100 feet in diameter and has a discharge estimated at from 8 to 10 cubic feet per second. Another large spring is directly on the bank of the river, at the town of Fishspring. Here there are a number of small streams flowing from crevices in the rock, the aggregate volume being 7 or 8 cubic feet per second. The peculiar feature with reference to this spring—for which it and the town were named—is that in the autumn, when the water of the river begins to grow cold, a large number of fish, especially sun perch, come from the river and enter the basin of the larger spring—a cavern beneath the surface of the earth—where they spend the winter, returning to the river after spring opens and the river water is again warm. Twenty-one hundred fish were caught in one season by means of a trap placed at the mouth of this spring when the fish were returning to the river, and 165 have been caught in a single night, all being very fat. This indicates the existence of a body of water of considerable size beneath the surface of the earth. This supposition is borne out by the fact that about 40 feet from the river an area probably 25 feet square has sunk several feet within the last few years, and a hole has opened in about the center of the depression through which fish can in the winter be caught by means of a hook and line.

TIMBER.

There is a great deal of valuable timber still standing in the basin of the Watauga, only about one-third of the area being cleared and in cultivation. The character of the timber varies as the stream is ascended, hard wood seeming the predominant growth along the lower part of the stream and its tributaries, but gradually giving place to pine, spruce, or hemlock. On the upper part of Laurel Creek and of the main stream, upon which the most extensive timbering operations have been carried on, the growth seems composed entirely of the latter trees, and the yield of timber is heavy. Evidences of extensive timbering are to be seen over almost the entire basin, the river at the time of both visits—one in the summer and the other in the fall—being full of logs waiting for a rise in the stream to carry them down to the mills. Numerous splash dams have been built on the tributaries and several on the river itself.

MINERALS.

Not many minerals or mineral localities are reported from this basin, the only place where mining rises to the dignity of an industry being at the famous iron mines at Cranberry, N. C., where is mined an iron which rivals in quality and purity the best Swedish ore. There are other deposits of iron ore in the basin, those on the upper part of Roan Creek and on Doe Mountain being perhaps the most noted. Formerly some copper was mined at Elk Knob, just beyond the eastern limits of the basin, but nothing has been done there for several years.

TRANSPORTATION.

The transportation facilities for the greater part of the basin are entirely inadequate. The East Tennessee and Western North Carolina Railroad, from Johnson City, Tenn., to Cranberry, N. C., furnishes an outlet for the products of that part of the basin, and the Virginia and Southwestern Railroad, from Bristol to Elizabethton and thence up Watauga River and Roan Creek, serves the northern part of the basin, but the whole area within North Carolina possesses no railroad, its facilities for transportation being limited to the country roads, which with the exception of the one paralleling the river are very poor, being steep, rough, and full of stones, so that it is impossible for a team to haul more than half a load over them. It is thought, however, that this condition will soon be bettered by the construction of a railroad from Lenoir, N. C., to Blowing Rock, and thence across the basin, probably following the course of the river a considerable distance and connecting with other roads, either at Cranberry, Butler, or Mountain City. Watauga County has recently authorized a bond issue of $100,000 to aid in the construction of this road.

DISCHARGE MEASUREMENTS.

During the investigation a gaging station was established on Watauga River at Butler, Tenn., and on two of its tributaries—

Roan Creek at Butler, Tenn., and Elk Creek at Lineback, Tenn. The results of measurements at these stations, as well as of the numerous miscellaneous measurements on the river and its tributaries, are given herein; those made on the main river in the following table, and those on the tributaries in the table on page 85.

Discharge measurements of Watauga River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 16	Elizabethton, Tenn	E. W. Myers	15.87	450
Aug. 2	do	L. V. Branch	15.77	593
Aug. 16	do	do	16.03	406
Oct. 5	do	E. W. Myers	16.08	348
Nov. 7	do	L. V. Branch	15.27	906
Dec. 28	do	E. W. Myers	15.68	533
Dec. 31	do	Ernest Graves	15.22	973
July 30	Butler, Tenn	E. W. Myers	1.37	434
Aug. 7	do	L. V. Branch	0.90	214
Aug. 17	do	do	0.84	166
Oct. 6	do	E. W. Myers	1.12	238
Nov. 7	do	L. V. Branch	2.20	591
Dec. 28	do	E. W. Myers	1.40	311
July 16	Watauga Falls, N. C	N. C. Curtis		79
Aug. 10	do	L. V. Branch	6.62	53
Oct. 7	do	E. W. Myers	6.52	60
Aug. 11	One mile above Shulls Mill, North Carolina.	L. V. Branch	4.05	19
Oct. 7	do	E. W. Myers	3.78	23

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made at Butler, Tenn. In making the other measurements in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

The fall of the Watauga River is very great throughout its length, and the selection of shoals for utilization would be largely a matter of convenience, the average fall of the stream in Tennessee being about 15 feet to the mile, and between Shulls Mill and the Tennessee line about 47 feet to the mile, with many short stretches where the fall is much greater. Very little of the vast power in this basin is utilized, however, either on the river or on its tributaries, there being, so far as could be ascertained, only three mills on the main stream, and these all small ones. The first mill is at Watauga Falls. It is a roller flour mill with a capacity of 30 barrels per twenty-four hours. The second one is just below the mouth of Cove Creek, where there is a fall of about 9 feet and a very good location for the construction of dams and buildings. Here there is a small sawmill and wagon shop which uses a small proportion of the water by means of a homemade tub wheel yielding an unknown amount of power.

The first shoal that could be developed into a power of considerable magnitude is just above the North Carolina line, where there is a fall of about 10½ feet, but it is in a deep gorge and at present is so inaccessible that it is of no importance as a power site.

For about 4 miles above this place, or as far as the mouth of Beech Creek, the concentration of fall is very great, and dams of almost any desired height could be built without excessive lengths across the top, and powers could be obtained limited only by the heights of the dams. There is a similar locality just below the mouth of the lower Laurel Creek.

Above this point and on through Valle Cruces there are a number of shoals in the river, but the average fall in the stream is less than that above or below, and since the bottoms are very broad and lie only a few feet above the water level, power could not advantageously be obtained in this part of the course of the river, on account of the flooding of valuable farming lands.

As has been stated, the gorge is redeveloped on a smaller scale a short distance above Valle Cruces, and the slope of the stream becomes very great, being a succession of rapids with large fall and many abrupt plunges. There are a number of places where a dam from 60 to 70 feet high could be built with stone quarried on the spot, while the level tops of the hills would afford a safe and excellent location for buildings; but until this country has made material advances and has provided means of transportation for raw materials and finished products, it is extremely improbable that any development of water power will be made beyond small amounts for purely local needs.

TRIBUTARIES OF WATAUGA RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the tributaries of Watauga River, in order upstream:

Discharge measurements of tributaries of Watauga River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 19	Brush Creek	Near Carter, Tenn	L. V. Branch	6.77	10.03
Aug. 16	do	do	do	6.82	9.47
Sept. 24	do	do	E. W. Myers	6.94	5.14
Aug. 2	Sinking Creek	Lower ford of Johnson City-Elizabethton road, Tennessee.	L. V. Branch	3.73	5.0
Oct. 4	do	do	E. W. Myers	3.75	4.0
Aug. 2	Buffalo Creek	At mouth, Tennessee	L. V. Branch	5.85	20.0
Oct. 4	do	do	E. W. Myers	5.92	10.0
Aug. 2	Gap Creek	do	L. V. Branch	4.00	7.0
Oct. 4	do	do	E. W. Myers	4.12	3.0
Aug. 3	Laurel Fork of Doe River.	Allentown, Tenn	L. V. Branch	5.19	30.0
Aug. 17	do	do	do	5.50	15.0
Oct. 5	do	do	E. W. Myers	5.67	9.0
Dec. 29	do	do	do	5.05	27.0
Aug. 3	Little Doe River	do	L. V. Branch	4.42	35.0
Oct. 5	do	do	E. W. Myers	4.78	17.0
Dec. 29	do	do	do	4.30	28.3
Aug. 3	Wilson Creek	One mile above mouth, Tennessee	L. V. Branch	3.67	5.0
Do	Shell Creek	At mouth, Tennessee	do	2.85	14.0
Do	Doe River	Two miles below Roan Mountain, Tennessee.	do	8.46	41.3
Do	do	Near Allentown, Tenn	do	5.56	72.0
Aug. 18	do	do	do	5.81	50.0
Oct. 5	do	do	E. W. Myers	5.85	39.3
Aug. 2	do	Above Elizabethton, Tenn	L. V. Branch	5.94	143.4
Aug. 17	do	do	do	6.20	106.0

Discharge measurements of tributaries of Watauga River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Oct. 5	Doe River	Above Elizabethton, Tenn	E. W. Myers	6.23	82.0
Dec. 31	.....do	.....do	Ernest Graves	5.23	304.0
Aug. 3	Stony Creek	One-half mile above mouth, Tennessee.	L. V. Branch	6.95	44.0
Oct. 5	.....do	.....do	E. W. Myers	7.59	16.0
Dec. 31	.....do	.....do	Ernest Graves	4.60	48.0
Aug. 13	Doe Creek	Ivyspring post-office, Tenn	L. V. Branch	5.94	9.0
July 30	.....do	Mouth of Doe (town), Tenn	E. W. Myers	5.23	59.0
Aug. 13	.....do	.....do	L. V. Branch	5.49	26.2
Oct. 9	.....do	.....do	E. W. Myers	5.46	28.38
July 30	Mill Creek	At mouth, Tennessee	.....do	9.48	13.0
July 29	Town Creek	At Shoun Crossroads, Tenn	L. V. Branch	3.48	29.2
Aug. 18	.....do	.....do	.....do	3.82	6.0
Do	Forge Creek	Near mouth, Tennessee	.....do	4.53	7.0
July 30	Roan Creek	Butler, Tenn	E. W. Myers	1.47	137.0
Aug. 7	.....do	.....do	.....do	1.02	65.0
Aug. 17	.....do	.....do	.....do	0.85	58.0
Oct. 6	.....do	.....do	.....do	0.86	52.0
Nov. 7	.....do	.....do	.....do	1.50	171.0
Dec. 28	.....do	.....do	.....do	1.20	82.0
Aug. 13	.....do	Key Station, Tenn	L. V. Branch	4.85	5.2
July 30	.....do	Above mouth of Mill Creek, Tennessee.	E. W. Myers	5.70	60.3
Aug. 6	Dark Ridge Creek.	One-half mile above mouth, Tennessee.	L. V. Branch	4.65	3.0
Do	Little Elk Creek	At mouth, North Carolina	.....do	1.20	6.0
Aug. 4	Blevins Creek	Cranberry, N. C	.....do	6.03	5.05
Do	Cranberry Creek	.....do	.....do	6.95	5.09
Aug. 12	North Fork of Elk Creek.	At Banners Elk, North Carolina	.....do	5.61	7.0
Oct. 8	.....do	.....do	E. W. Myers	5.64	4.0
Aug. 11	South Fork of Elk Creek.	.....do	L. V. Branch	11.96	9.35
Oct. 8	.....do	.....do	E. W. Myers	11.82	8.48
Aug. 9	Elk Creek	Lineback, Tenn	.....do	3.5	70.0
Aug. 17	.....do	.....do	.....do	3.5	56.0
Oct. 6	.....do	.....do	.....do	3.5	53.0
Aug. 6	.....do	One-half mile below mouth of the Little Elk, Tennessee.	L. V. Branch	7.21	64.0
Aug. 9	Big Dry Run	One-eighth mile above mouth, North Carolina.	.....do	1.55	0.85
Do	Fogey Creek	At mouth, North Carolina	.....do	2.94	1.4
Oct. 6	.....do	.....do	E. W. Myers	3.02	2.4
Aug. 9	Beech Creek	Above mouth of Fogey Creek, North Carolina.	L. V. Branch	5.6	7.3
Oct. 6	.....do	.....do	E. W. Myers	5.7	7.4
Aug. 9	Beaverdam Creek.	Near Leander, N. C	L. V. Branch	5.59	7.0
Oct. 6	.....do	.....do	E. W. Myers	....	8.0
Aug. 10	Laurel Creek (lower).	At mouth, North Carolina	L. V. Branch	10.62	4.0
Oct. 7	.....do	.....do	E. W. Myers	....	3.09
Aug. 12	Rockhouse Creek	.....do	L. V. Branch	2.17	16.3
Oct. 18	.....do	.....do	E. W. Myers	....	0.8
Aug. 12	Brushy Fork of Cove Creek.	.....do	L. V. Branch	2.06	5.19
Do	Cove Creek	Above mouth of Brushy Fork, North Carolina.	.....do	4.31	23.0
Aug. 10	.....do	At mouth, North Carolina	.....do	5.24	12.0
Oct. 7	.....do	.....do	E. W. Myers	5.15	14.0
Aug. 10	Dutch Creek	Valle Cruces, N. C	L. V. Branch	7.42	11.0
Oct. 7	.....do	.....do	E. W. Myers	7.37	6.0
Aug. 10	Laurel Creek (upper).	At mouth, North Carolina	L. V. Branch	2.62	10.0
Oct. 7	.....do	.....do	E. W. Myers	2.87	6.0
Aug. 11	Moody Mill Creek.	.....do	L. V. Branch	3.20	4.0
Aug. 10	Boone Fork of Watauga River	Shulls Mill, N. C	.....do	2.30	12.0
Oct. 7	.....do	.....do	E. W. Myers	2.11	13.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made of Roan Creek at Butler, Tenn., and of Elk Creek at Lineback, Tenn. In making the other measurements in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

BRUSH CREEK.

The first tributary of the Watauga which was made the subject of investigation was Brush Creek, which rises near Johnson City, Tenn., and flowing in a general northwesterly direction joins the Watauga a short distance below Carter, Tenn., having a total length of between 7 and 8 miles and draining an extensive area. The drainage basin consists of large but low hills with very gentle slopes, largely grass covered. Probably 90 per cent of the area is cleared land, largely in pasture, but a small part is cultivated in corn and wheat. The soil is deep and fertile. The country rock is a limestone.

The creek has a fall of about 400 feet between Johnson City and its mouth. The water is used by two small mills, too small to be of importance, and there is no definite information concerning them at hand. It is probable that this creek reached its minimum stage in September, 1900, when it was discharging about 5 second-feet. During floods it rises about 3 feet above low-water mark at its mouth.

SINKING CREEK.

The upper or second Sinking Creek, which enters from the south, is the next tributary. It drains a narrow area between 10 and 11 miles long, about three-fourths of the lower part of which is cleared. Its headwaters drain the northwestern slopes of the Buffalo and the Cherokee mountains, a rough and rugged area, densely forested. The characteristics of soil and topography over the lower part of the basin are in every way similar to those of the basin of Brush Creek. The stream was very low at the time it was visited, early in October, attaining its lowest stage during that month. It was carrying 4 second-feet when measured on October 4. During floods it rises about 2 feet.

BUFFALO CREEK.

Buffalo Creek, the next tributary, drains a much larger area than either Brush Creek or Sinking Creek. The greater part of its drainage basin consists of low, flat, and rounded hills, for the most part grass covered. Probably from 85 to 90 per cent of the lower portion of the basin is cleared; but as the stream is ascended the country becomes more rugged, being very steep and mountainous near the headwaters, and is largely covered with forest, though it is probable that three-fourths of the entire area drained by the stream is cleared. It is in the basin of this stream that the great number of sinks which have heretofore been mentioned as occurring near Milligan are to be found. These sinks occur from Milligan to the east and southeast as far as Gap Creek. At the time of the fall visit (October 4, 1900) the stream had reached its lowest stage of flow (10 second-feet). Its maximum flood rise is about 3 feet.

Buffalo Creek has three small tributaries—Dry Creek, Toll Creek, and Powder Branch—all of which enter from the southeast.

GAP CREEK.

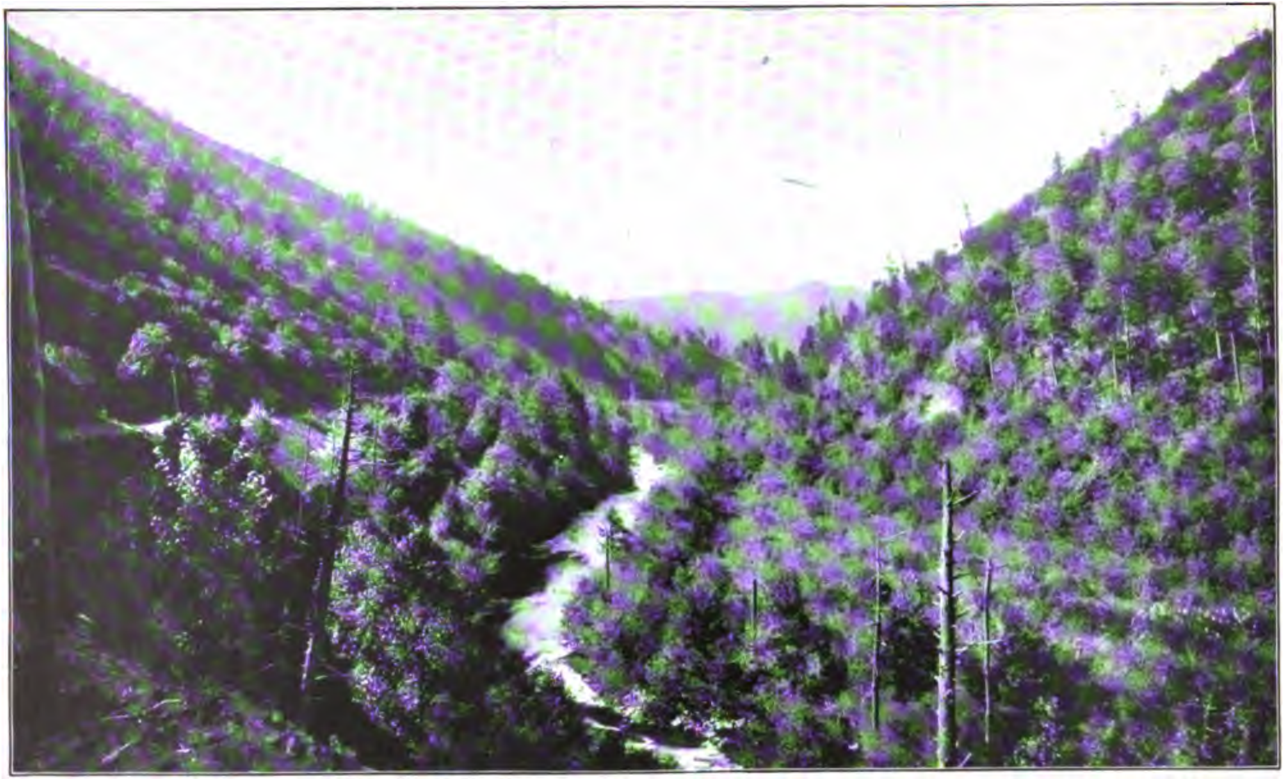
Gap Creek, the next tributary entering the Watauga from the south, has a drainage basin which seems in every way similar to that of Buffalo Creek, with the exception that no sinks were seen. This stream reached its minimum stage in the fall of 1900. When measured on October 4 it was discharging 3 second-feet. Its flood rise is about 3 feet at the mouth.

DOE RIVER.

The most important tributary received by Watauga River is Doe River, which rises in the high and mountainous area to the west and north of Roan High Knob, and flows in a general northerly and northwesterly direction, joining the Watauga at Elizabethton, Tenn. Near the mouth of the stream probably one-forth or more of the valley is cleared land, the cleared areas being the level bottom or terrace land immediately along the river; but about 2 miles above Elizabethton the gorge of the Doe begins, and from that point to Allentown the river flows in a very narrow channel carved out by its waters from the solid rock, which rises on either side in precipitous walls several hundred feet high. Near Allentown, where Doe River is joined by the Laurel Fork and Little Doe River, there is a considerable area of open and level arable land rimmed about by high and steep mountains. Above that place the gorge of the Doe becomes more pronounced, the sides rising higher and more steeply above the water, and the scenery, though confined, is very much grander than that of the lower gorge. A view in the upper gorge is shown in Pl. XXIII. Throughout the gorge the fall averages nearly or quite 100 feet to the mile, the greater part of it being in rapids; sudden plunges are rare. Power in large amounts could be obtained here. Above the gorge the fall averages about half as much, being about 50 feet to the mile.

The water power of Doe River is used at only two places. At Elizabethton water is taken from the stream above the town and is used in the operation of a small cotton mill and several small gristmills. A small woolen mill is also sometimes operated by power derived from the stream. The largest consumer of power was a woolen mill which was burned several years ago and has not been rebuilt. Near Roan Mountain Station there is a small lumber mill using three turbines working under a head of 12 feet, but the amount of power developed could not be ascertained.

Little Doe River.—This stream, which is tributary to Doe River at Allentown, drains an area in all respects similar to that drained by the main stream above the junction, being very mountainous and largely forest covered. So far as could be ascertained there is prac-



DOE RIVER VALLEY, TENNESSEE.

tically no cleared land above 2 miles from its mouth. None of the power of the river is utilized. The time of minimum flow was in September, 1900. The flood rise at the mouth is about 4 feet.

Laurel Fork.—The next important tributary of Doe River is the Laurel Fork, which joins it at Allentown, draining an area similar to that drained by the main stream and by the Little Doe. The Laurel Fork has a large fall and carries a considerable quantity of water, which is used at Allentown by a small sawmill, and just above that place by a combined sawmill and gristmill using a small amount of power and a fall of 16 feet. Another mill is reported farther upstream. It is stated that active lumbering operations are now in progress over the basin of the Laurel Fork and that much timber has been cut.

STONY CREEK.

The next tributary of the Watauga is Stony Creek, which enters the river from the northeast and drains a long and broad valley containing a larger proportion of cleared and cultivated land than either of the streams just described. The cleared land, however, is confined to the level bottoms bordering the creek and to the first bench or terrace—this being all that is susceptible of cultivation, so it is said—and amounts to only about one-eighth of the whole, the remainder of the basin being steep, rugged, and forest covered. At the time of the October visit the stream was said to have reached a point lower than ever before known. It was then carrying 16 second-feet. The high-water mark is about 6 feet above its level at that time.

The average fall of the stream is large, and its waters are used by several mills, all small, the first one being located close to the mouth of the creek and using a fall of 10 feet, the power developed being estimated at about 12 horsepower. The second mill is a short distance above and is a small corn mill operated by a homemade wheel developing an unknown amount of power. The third mill is about a mile above the mouth of the stream and is a small combined sawmill and gristmill using a small amount of power.

ROAN CREEK.

There is no other important tributary of the Watauga until Roan Creek is reached. The watershed of this stream, which joins the river at Butler, Tenn., is in the area between the Stone Mountains on the north and Snake Mountain on the south. The main stream rises near Snake Mountain and flows in a general northerly direction for 7 or 8 miles, when it is joined by Forge and Town creeks—streams which rise in the Stone Mountains and flow to the south—and turns to the southwest, flowing in that direction until its junction with the Watauga. In the latter portion of its course it receives one large tributary, Doe Creek. Roan Creek drains a very large area, known as Johnson County Cove, which has already been somewhat briefly described (p. 38). The immediate valley of the creek contains practically all of the cleared land in its basin, though small areas have been cleared on some of its minor tributaries where the land is sufficiently level for cultivation. All of the timbered area is still in luxuriant forest growth, consisting principally of oak and chestnut, though maple, locust, pine, spruce, hemlock, poplar, and similar trees are found. Probably 75 per cent of the area is still wooded. Near the mouth of the stream the valley is very narrow and the proportion of cleared land seems smaller than farther toward the headwaters, where the basin bears a close resemblance to the country along the South and Middle forks of the Holston, being rather level and composed of low, grass-covered hills, which are largely cleared. The mountainous areas are high and steep, showing a great deal of exposed rock and being in places densely forested.

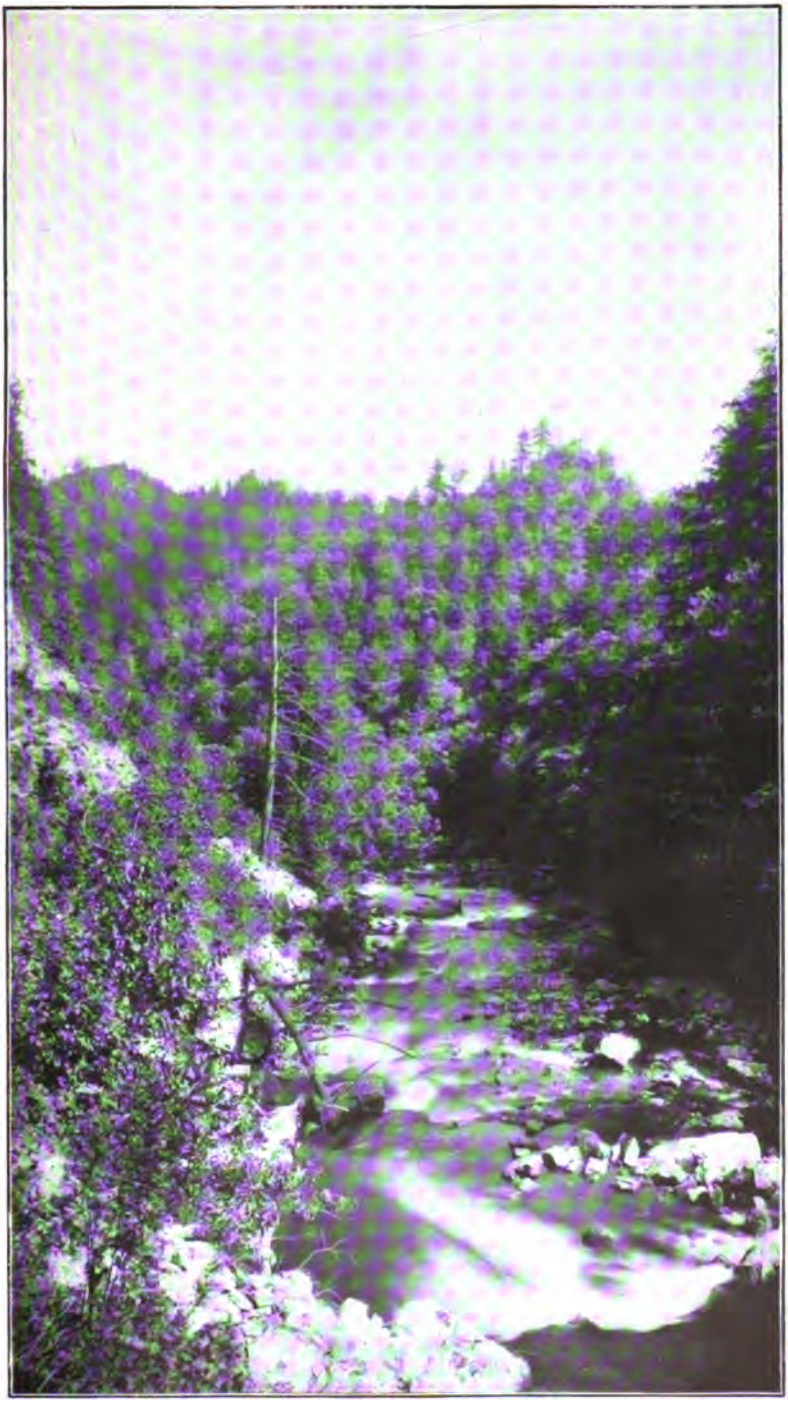
The fall of Roan Creek is considerable, being about 400 feet between the mouth of Doe Creek and a point about 2 miles below Mountain City, Tenn., a distance of 10 miles, making the average fall 40 feet to the mile. Between Shoun Crossroads and the mouth of Mill Creek, however, the fall is much less, and there are stretches where the current is very sluggish and the stream placid. The country rock is no longer a limestone—quartz rock, gneiss, and slate having made their appearance. Although this stream drains so large an area and has so great a fall its waters are used by very few mills.

The first mill on the stream is the roller flour mill operated by Cole & Scott, a short distance above Butler, which has a capacity of 30 barrels a day and is operated by a turbine working under a head of 12 feet. The next mill is 14 miles above Butler and is a combined gristmill and sawmill using a fall of 12 feet and a very small amount of power. The only other mill on the stream is Baker's gristmill, opposite Rhea Forge, where there is a fall of 18 feet.

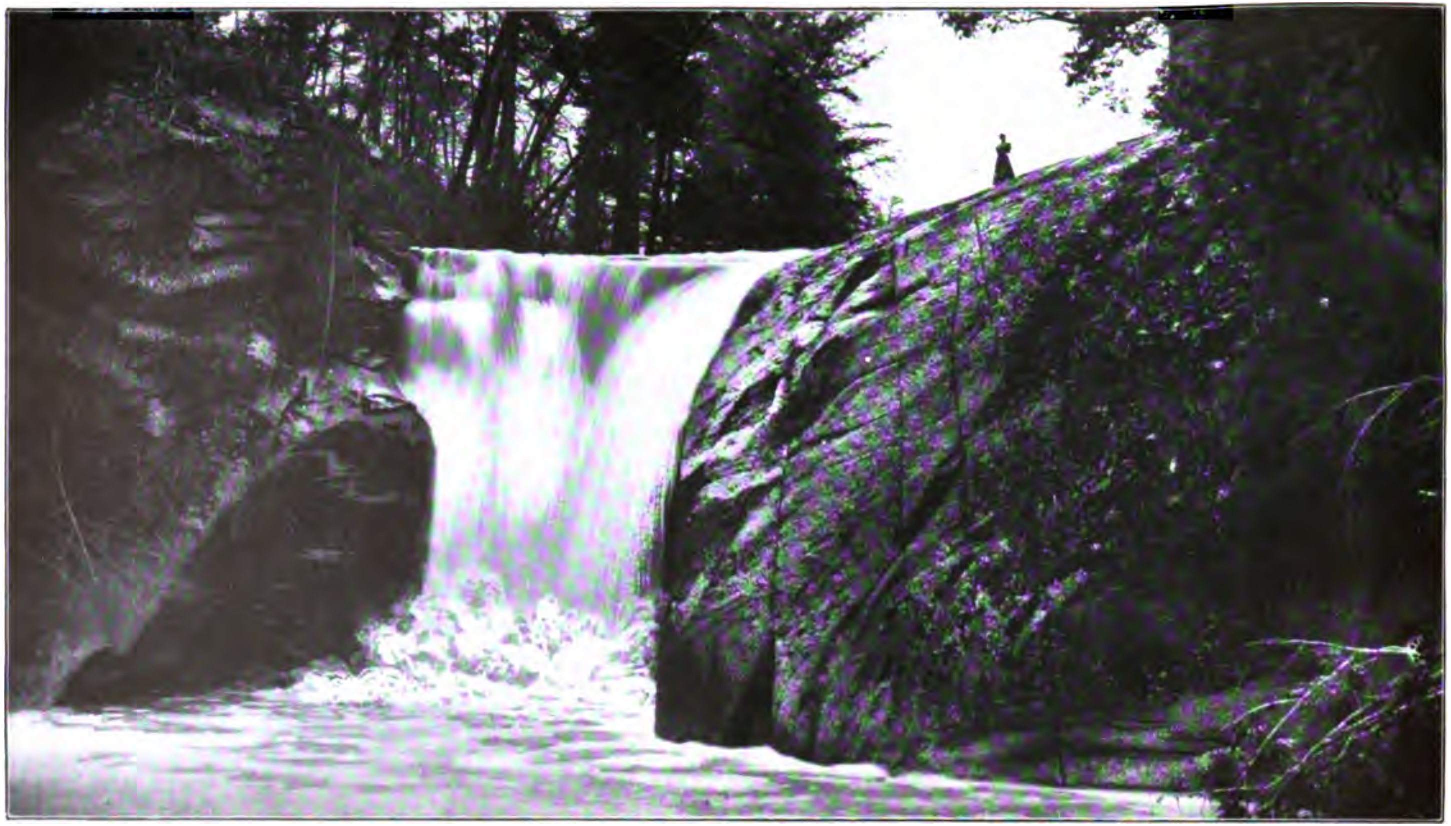
Roan Creek reached its minimum stage during the fall of 1900. It was measured on August 13 and was carrying 5.2 second-feet. The average flood rise is about 5 feet, though there are records of a much higher rise in 1861 and in 1870, when the stream rose to a height of 8 feet.

Doe Creek.—This stream rises near Mountain City, Tenn., and flows in a direction generally parallel to the course of Roan Creek, from which it is separated by Doe Mountain, joining that stream about 6 miles above Butler. It drains a broad, flat valley which forms a part of Johnson County Cove, and furnishes more utilized power than Roan Creek, its waters being used for the operation of seven small mills.

Mill Creek.—Of the numerous small streams tributary to Roan Creek from the east and southeast none seen were of sufficient importance to justify gaging with the exception of Mill Creek, which enters from the southeast near Baker Gap. This creek was gaged near its mouth and its drainage basin was traversed from end to end. Near



ELK CREEK, NORTH CAROLINA.



ELK FALLS ON ELK CREEK, NORTH CAROLINA.

Roan Creek the proportion of cleared land is very small, but farther up the basin widens, and near the stream all the land has been cleared and is cultivated in corn and wheat or sodded in grass. The cleared land amounts to between one-fourth and one-third of the total area drained by the stream. About 100 yards above the mouth of the creek is Wilson's gristmill, a small mill containing two runs of stones, one for corn and one for wheat, the power necessary being developed by a 16-foot overshot wheel of about 30 inches face, yielding about 12 horsepower.

Town Creek.—This was the only other tributary of Roan Creek that was gaged. It was measured at Shoun Crossroads. There is one small mill on the creek containing two runs of stones, one for corn and one for wheat, and using 5 or 6 horsepower, which is developed by an undershot wheel.

ELK CREEK.

The next important tributary of Watauga River is Elk Creek (see Pl. XXIV), which rises at Banner Elk Creek, on the slopes of the mountain known as Hanging Rock, and flowing in a general direction a little north of west is joined near Elk Park by Cranberry Creek and Little Elk Creek, after which it turns to the north, entering Watauga River about 2 miles above Butler. A gaging station was established on this stream at Lineback, not far above the mouth, where daily readings of the stage of the water surface have been made.

The average fall per mile throughout its length is very great, the headwaters being at an elevation of about 4,000 feet above sea level. Near the mouth the fall seems to be less than the average, and there are large areas of cleared land and broad, level bottoms, from which, however, the wooded mountain slopes rise very sharply to considerable heights. There are small tracts of cleared land as far up the stream as Elk Mills. Between that place and the North Carolina line there is practically no clearing, but beyond the State line the country is more thickly settled and the areas of cleared land are more numerous. The latter are, however, of little importance compared to the total area of the drainage basin. No accurate estimate of the relative proportions of the wooded and cleared lands could be obtained, but it seems safe to say that the amount of clearing is less than 5 per cent of the area.

The amount of power along this stream is very great, but no attempts have been made to utilize it, and it seems improbable that efforts in that direction will be made for many years to come, unless some sawmill requires power to cut the timber which exists in such abundance over the basin. Perhaps the most noteworthy of the powers is Elk Falls (see Pl. XXV), where there is one of the most picturesque bits of scenery to be found in this country. Here there is a straight plunge of 26 or 28 feet, and in the first mile below it the river falls 53 feet more, while in the 4 miles above it the fall averages 100 feet to the mile.

Above the latter point and as far as Banners Elk there are numerous shoals and rapids which would furnish small and compact powers with from 10 to 40 feet fall; but there is no demand for power in the present state of the country. Near the headwaters, and in particular near Banners Elk, the fall in the stream is very slight, the creek flowing through semimarshy areas and swampy meadows or peaty bogs covered with a dense growth of laurel, and the mountain slopes are covered with fine timber, spruce predominating, though many other varieties occur.

Throughout the basin the slopes are without exception steep, ranging as high as 50 degrees in some cases, and seem to be covered with a deep soil. The country rock over the lower part is a limestone, that of the upper part gneiss and quartz rock. The soil of the immediate valley is fertile and well adapted to agriculture, the principal crops being grass, corn, and wheat, with some buckwheat and sorghum cane. Many varieties of very fine apples are also grown.

The area being so largely forested the flow of the stream is large, the water never falling very low nor rising to great heights, and though the slopes are steep the high water lasts several days. The creek rises about 5 feet at the mouth.

The famous iron mills at Cranberry are located within the basin of this stream.

BEECH CREEK.

The next stream tributary to the Watauga is Beech Creek, which rises on the northern slopes of Beech Mountain, at an elevation of about 5,000 feet, and flows in a general northwesterly direction, joining the river about 4 miles above the State line. It drains a considerable area of steep, high, and densely forested mountain slopes, a very small proportion of the land being cleared. The cleared areas are confined exclusively to a small tract in the basin of Fogey Creek, which joins Beech Creek a short distance above its mouth, and to some of the narrow bottoms and small hills along the main stream for 2 or 3 miles above its mouth. The total area cleared amounts to possibly 5 per cent of the whole basin. Near the mouth of the stream the country rock seems to be a very good quality of granite, but as the creek is ascended this soon gives place to gneiss. The stream never falls very low, and during high water it rises about 4 feet at the mouth, that being the elevation of the highest mark that was found.

BEAVERDAM CREEK.

Beaverdam Creek, the next tributary entering from the north, rises near Baker Gap and Locust Gap, and flowing in a general southeasterly direction joins the Watauga just to the west of the small mountain known as Dyer Knob. For a mile or more above its mouth this stream is in a deep gorge, the sides, which are very steep, rough, and rocky, and entirely wooded, rising from the water's edge. The fall of the stream in this gorge is considerable. None of it, however, is now used, but the remains of an old mill are to be seen. In this section and for some distance above Leander active timbering operations are now in progress, but so far very little timber seems to have been cut. Above this the valley widens, the hills are lower and the slopes less steep, and much of the land is cleared and under cultivation in grass or grain. On the fork which rises near Baker Gap almost all of the land is cleared except the tops of the hills and probably one-half or more of the country drained by the other forks. Of the total area drained by Beaverdam Creek probably one-half is cleared land, with a deep and fertile soil. The stream attained its minimum flow in the fall of 1900. The maximum rise at its mouth is about 4 feet.

LAUREL CREEK.

Laurel Creek is the next stream of importance to join the Watauga. It enters from the south, after draining a large basin. The creek valley is very rough and inaccessible for about 2 miles above its mouth, the gorge being deep and the sides in many cases sheer walls of rock. The fall in this distance is very great, being 600 or 700 feet. Above this the fall is much less, though it is still large, and a small part of the area has been cleared and placed under cultivation, the clearing being confined to the comparatively level lands lying near the stream and amounting to probably about 5 per cent of the whole basin. The hillside slopes are steep and forested and the soil is generally deep and fertile, although in some places it is shallow and full of rock fragments. Along the upper portions of the stream the soil is swampy in places and seemingly quite acid and in its present state unsuitable for cultivation.

Extensive lumbering operations have been begun in this basin and much timber has been cut on the hillsides, a great many logs being seen in the stream channel awaiting high water to carry them downstream.

It is said that this stream has never before reached a stage of flow as low as during the summer of 1900. The average flood height at the mouth is about 5 feet.

COVE CREEK.

Cove Creek, which enters the river from the north, is the principal tributary in this part of its course and one of the largest entering the stream. It rises near State Line Gap and flows in a general southerly direction for 14 or 15 miles, draining a broad and very fertile valley, which in comparison with the larger part of the watershed of Watauga River is thickly settled. It is estimated that about one-third or a little more of the basin is cleared land, largely in grass, as stock raising is the principal industry throughout this country, as it is farther to the north. Throughout this valley, with the exception of the mountain slopes to the east and west, the hillside slopes are rather gentle—rarely reaching 30 degrees, the average being not more than 20 degrees—and the bottom lands are broad, with a deep and fertile soil. While the soil of the hillsides is less fertile, it produces very good crops of wheat and corn. From an agricultural standpoint the basin of this stream seems to be more valuable than any part of the watershed of the Watauga yet described.

At times the creek reaches a very low stage of flow, but never lower, it is said, than that attained during the summer and autumn of 1900. The average maximum rise at the mouth is about 5 feet; 6 feet is sometimes reached, and there is one report of a rise of 8 feet several years ago, probably when a destructive flood affected the entire basin of the river.

DUTCH CREEK.

Above Cove Creek the first tributary is Dutch Creek, which enters the river at Valle Cruces. This creek rises on the southern slopes of Hanging Rock and flows in a general northerly direction, draining an area which is very largely forest covered, containing not more than 20 per cent of cleared land, which is for the most part confined to the comparatively level land immediately along the creek. The mountain slopes are high, steep, and quite rugged, and are covered with the original dense forest growth. Like the other streams of the region, the creek reached its lowest stage during the summer of 1900. Its maximum rise at the mouth is from 3 to 4 feet.

LAUREL CREEK.

Laurel Creek is a small tributary entering the Watauga from the northeast, about 2 miles north of Shulls Mill. It drains a very small area, but carries a large quantity of water in comparison with the area drained, the basin being almost entirely forest covered. The cleared land is confined to a few small areas close to the river, these forming less than one-eighth of the basin. The hillside slopes are rugged, steep, and very rocky, and for the most part are covered with a dense forest growth. The stream reached its minimum flow during the summer of 1900. It rises 3 feet in its maximum floods.

BOONE FORK.

Immediately above Shulls Mill the Watauga is divided into two forks, the one to the east being known as the Boone Fork and the one to the west as Watauga River. The Boone Fork rises on the eastern slope of Grandfather Mountain and after flowing almost due east for 3 or 4 miles turns to the north and flows in that direction for about 4 miles, or to its junction with the main fork of the Watauga. There are no roads along this stream, and its entire basin is inaccessible. The information that was gathered concerning it was obtained from persons dwelling in the country near by. The stream has a great fall, the headwaters rising at an elevation of about 5,000 feet, while the elevation at the junction with the Watauga is about 2,950 feet. Approximately 1,000 feet of this is concentrated in the first mile below the head of the stream, making the average fall per mile below that point between 165 and 170 feet. So far as could be learned none of the fall is used except by the Stonewall mill, a small sawmill and gristmill just above the junction with the Watauga. The sawmill is operated by a Leffel turbine yielding 15 horsepower under a head of 12 feet, which at low stages of the stream requires practically all of the water flowing. The gristmill is operated by three homemade center-discharge wheels working under the same head, but the amount of power given off by them could not be ascertained.

The entire area drained by the Boone Fork is high, rugged, and very mountainous, almost entirely covered with a dense and luxuriant forest growth. The soil is deep and porous, holding back the storm waters to some extent and feeding them out gradually to the stream, which has a large flow, never falling very low. Notwithstanding the great slope of the stream bed and of the hillside slopes, the floods are not so violent as would be expected.

In Part II of this paper, published as Water-Supply and Irrigation Paper No. 63, will be found descriptions of the drainage basins and water powers of the Nolichucky, the French Broad, the Saluda, the Broad, the Catawba, the Yadkin, the New, and other streams of the region.

[For index, see end of Part II, Water-Supply Paper No. 63.]

O

DEPARTMENT OF THE INTERIOR

Walter Mulford

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 63

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

Walter Mulford

HYDROGRAPHY

OF THE

SOUTHERN APPALACHIAN MOUNTAIN REGION

PART II

By HENRY ALBERT PRESSEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

CONTENTS.

Page.

- Drainage basins—Continued 105
  - Nolichucky River 105
    - Physical features 106
    - Rainfall 106
    - Forests 106
    - Minerals 106
    - Discharge measurements 107
    - Water powers 107
  - Tributaries of Nolichucky River 108
    - Discharge measurements 108
    - North Indian Creek 110
    - South Indian Creek 110
    - Hollow Poplar Creek 111
    - North Toe River 111
    - South Toe River 114
    - Caney River 114
  - French Broad River 115
    - General features 115
      - Watershed in North Carolina 116
      - Watershed in Tennessee 121
    - Rainfall 123
    - Transportation 124
    - Discharge measurements 124
    - Water powers 125
  - Tributaries of French Broad River 127
    - Discharge measurements 127
    - Long Creek 129
    - Big Creek 129
    - Laurel Branch, Mooneyham Branch, and Rock Creek 129
    - Wolf Creek 129
    - Shutin Creek 130
    - Spring Creek 130
    - Big Laurel Creek 130
      - Shelton Laurel Creek 131
    - Big Pine Creek 131
    - Walnut, Little Pine, and Hayes creeks 132
    - Ivy River 132
    - Sandymush Creek 134
      - Turkey Creek 134
    - Flat Creek 134
    - Reems, Newfound, and Beaverdam creeks 135
  - Saluda River 135
    - North Saluda River 136
    - Middle Saluda River 137
    - South Saluda River 137
    - Discharge measurements 138
  - Broad River 139
    - Physical features 139
    - Rainfall 140
    - Forests 140

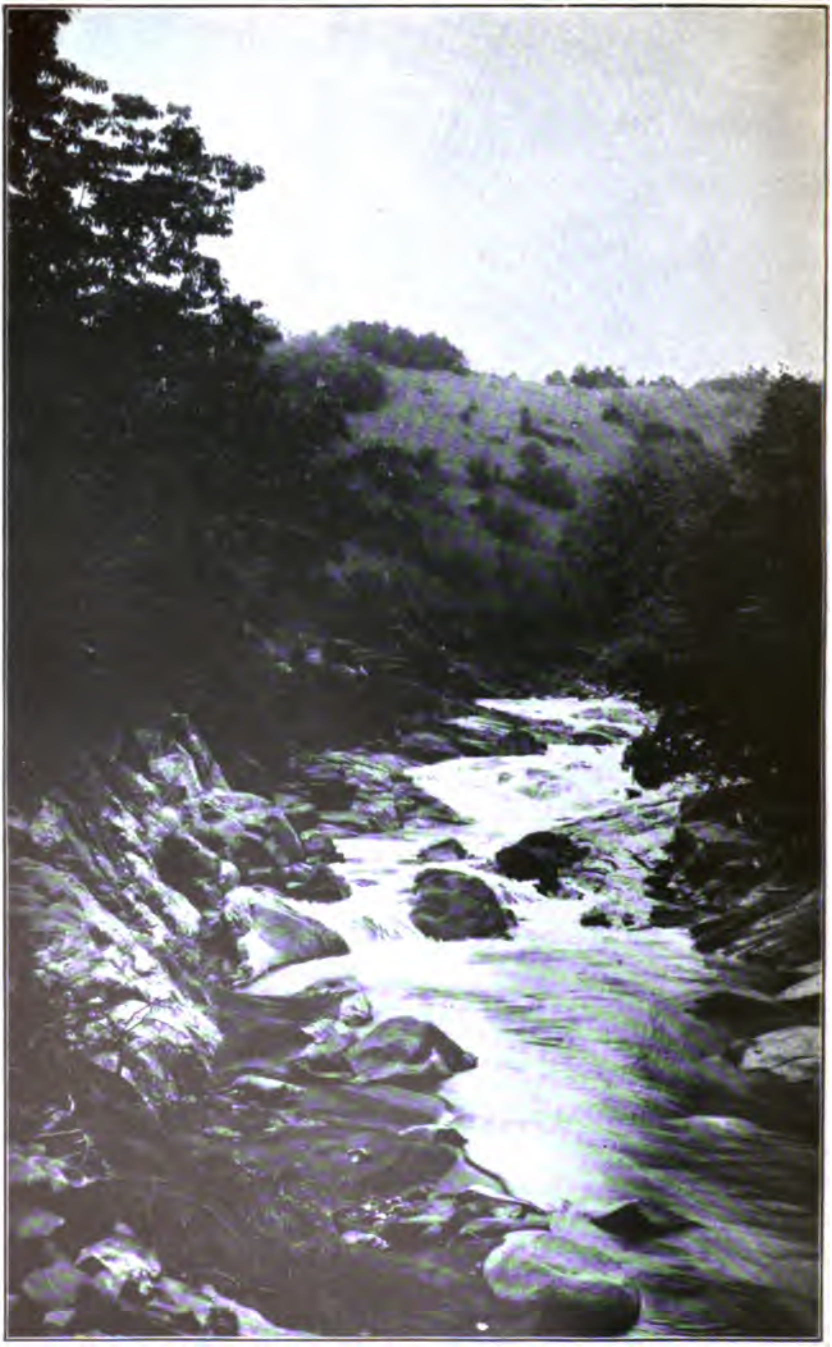
Drainage basins—Continued. Page.

Broad River—Continued.

Minerals 140
Discharge measurements 141
Water powers 142
Tributaries of Broad River 143
Discharge measurements 143
First Broad River 143
Second Broad River 144
Green River 145
Catawba River 147
Physical features 147
Rainfall 148
Forests 148
Discharge measurements 148
Water powers 150
Tributaries of Catawba River 151
Discharge measurements 151
Center, Crib, Clear, and Buck creeks 152
North Fork of Catawba River 153
Paddy Creek 153
Linville River 153
Cane Creek 155
Upper Creek 156
John River 157
Lower Creek 158
Yadkin River 158
Physical features 158
Soils 160
Forests 161
Discharge measurements 161
Water powers 162
Tributaries of Yadkin River 164
Discharge measurements 164
Elk Creek 165
Stony Creek 165
Louis Fork 165
Unnamed tributary east of Louis Fork 166
Reddie River 166
Mulberry River 166
Roaring River 167
Big Elkin River 167
Mitchell River 168
Fisher River 168
Ararat River 169
New River 169
South Fork of New River 171
General features 171
Discharge measurements in basin 172
Water powers in basin 173
North Fork of New River 173
General features 173
Discharge measurements in basin 174
Water powers in basin 174
Streams southwest of French Broad River 175
Index 183

ILLUSTRATIONS.

		Page.
PLATE XXVI.	Cane Creek, tributary of Nolichucky River, showing characteristic rocky bed of mountain streams	105
XXVII.	Gorge of Nolichucky River	106
XXVIII.	View showing effect of floods on Nolichucky River	106
XXIX.	*A*, Splash dam on Little River, Tennessee; *B*, Combined sawmill and gristmill on Price Creek, Yancey County, N. C	108
XXX.	Swannanoa Rapids on Swannanoa River, North Carolina	118
XXXI.	French Broad River at Paint Rock, N. C	120
XXXII.	Mountain Island Shoal, French Broad River, North Carolina	124
XXXIII.	Hickory Nut Gap from Chimney Rock, North Carolina	140
XXXIV.	Hickory Nut Creek, North Carolina	140
XXXV.	Falls on upper Catawba River, North Carolina	146
XXXVI.	*A* and *B*, Views showing hillside wash in valley of Catawba River	148
XXXVII.	*A*, View showing removal of soil in valley by floods; *B*, View in valley of Catawba River, showing destruction by floods	148
XXXVIII.	Lower falls of Linville River, North Carolina	154
XXXIX.	Lower falls of Cullasagee Creek, North Carolina, a tributary of Little Tennessee River	174
XL.	Oconalufty Valley, North Carolina	174
XLI.	Tuckasegee River near Dillsboro, N. C	176
XLII.	Tuckasegee Falls, North Carolina	176
XLIII.	Water-power development on Tuckasegee River near Painter, N. C	178
XLIV.	Okoee River near Ducktown, Tenn	178



CANE CREEK, TRIBUTARY OF NOLICHUCKY RIVER, SHOWING CHARACTERISTIC ROCKY BED OF MOUNTAIN STREAMS.

HYDROGRAPHY OF THE SOUTHERN APPALACHIAN MOUNTAIN REGION.

PART II.

By HENRY A. PRESSEY.

DRAINAGE BASINS—Continued.[a]

NOLICHUCKY RIVER.

PHYSICAL FEATURES.

This river is formed by the junction of Toe River and Caney River about 8 or 9 miles east of the Tennessee State line. Toe River is formed by the union of the North Toe and the South Toe between Sevenmile Ridge and the Burn Mountains. The area drained by the Nolichucky in North Carolina is in the high mountains within the limits of Yancey and Mitchell counties.

Yancey County is preeminently mountainous, the Black Mountains penetrating it from the southeast and extending to its center, or to near Burnsville. The great Unaka Range separates the county from Tennessee, and numerous cross chains intersect its surface in all directions, leaving very little valley land except along the banks of the streams. As elsewhere in the region, the mountains here are fertile to the top, being covered with a deep and friable soil which bears trees of great size, and where cultivated produces all of the grains and grasses, as well as very excellent fruits, the apples being especially fine. Cattle raising is an important industry.

Mitchell County lies between the Blue Ridge on the south and east and the Unakas on the north, and like Yancey County is very mountainous, there being little valley land except along the headwaters of Toe River. The cultivated lands are very fertile. All of the cereals grow well, grasses flourish, and fruits of very fine quality are produced in abundance.

The tributaries, like the main stream, rise near the summits of the mountain chains and flow over rocky and precipitious beds through narrow valleys. One of these rocky stream beds is shown in Pl. XXVI, a view of Cane Creek, one of the large tributaries of the Nolichucky.

---

[a] Continued from Part I, Water-Supply Paper No. 62.

The river first flows almost north for several miles, then turns toward the northwest and flows in a deep gorge through the Unaka Mountains (see Pl. XXVII) and into Tennessee, where preserving its general westerly direction it finally enters French Broad River about 7½ miles southeast of Morristown, draining a total area of 640 square miles above the Tennessee line, comprising almost all of Mitchell County and all of Yancey County. It leaves the mountains near Embreville, Tenn., which was the western limit of the investigation, although some observations were made of the character of the country lying to the west, sufficient to establish the fact that it differed in no important respects from the area already described as the Valley of East Tennessee.

None of the small closed drainage basins or sinks which are so numerous in the valley of the Holston were seen in the basin of the Nolichucky, but there seems to be a greater number of large springs.

RAINFALL.

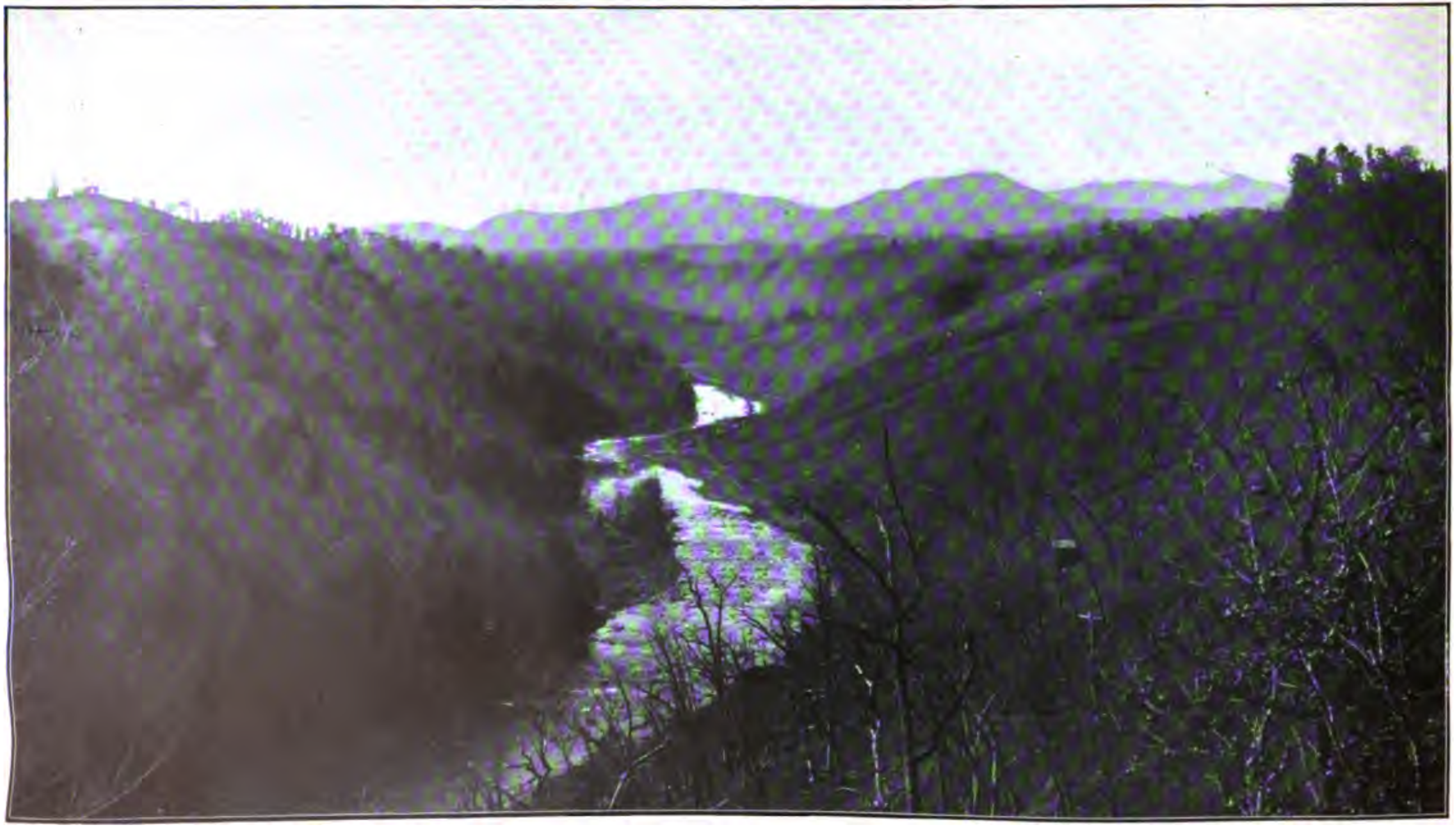
The rainfall over the basin is about 51.2 inches per annum, 11.4 inches of which falls in the spring, 15.7 inches in the summer, 11.6 inches in the autumn, and 13.5 inches in the winter. The whole area is subject to sudden and violent rains, producing great floods, while in the winter the ice moving downstream sometimes forms ice dams which do a great deal of damage. The streams are therefore of much less value as sources of power than they otherwise would be. The effect of floods on the Nolichucky is shown in Pl. XXVIII.

FORESTS.

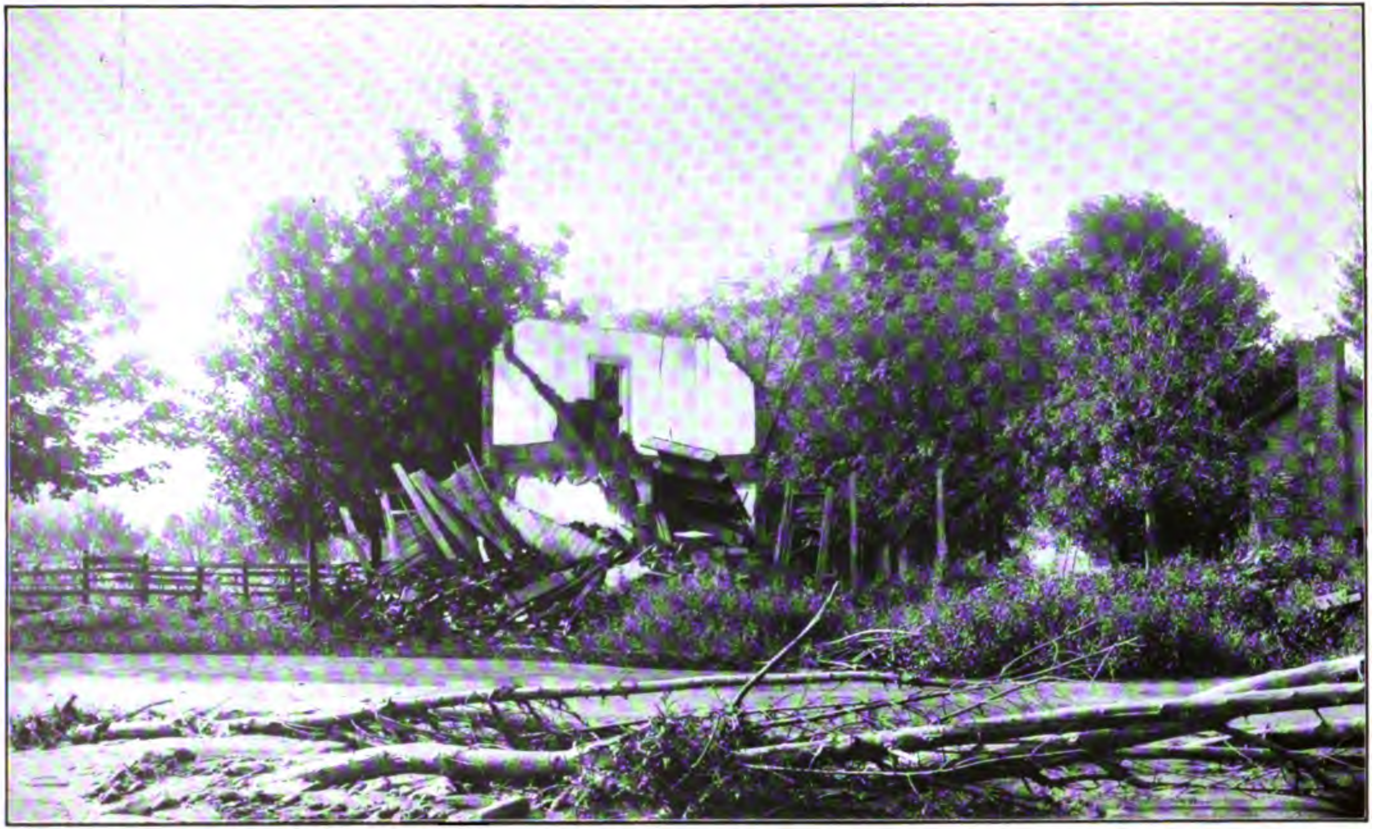
A very large part of the basin is still covered with the original forest. It is estimated that of the 640 square miles in North Carolina 78 per cent is forested, owing, doubtless, to the inaccessibility of the country. It is thought, however, that deforestation will begin in the near future, since in the summer of 1900 the Ohio River and Charleston Railroad was completed as far as the mouth of Caney River, and it is probable that the area drained by that stream will be lumbered at once, as already small spasmodic efforts in that direction have been made. Small sawmills run by water power have been built on a number of the smaller tributaries, and in a few instances splash dams have been constructed for the purpose of driving the logs over the rocky ledges of the mountain streams. Pl. XXIX, *A*, shows a splash dam on Little River, Tennessee, which raises the water 35 feet. Pl. XXIX, *B*, shows a characteristic combined sawmill and gristmill of Yancey County, with its immense overshot wheel.

MINERALS.

The area is very rich in minerals, Mitchell and Yancey counties, as already stated, furnishing a large part of the world's supply of mica. Many varieties of gems also occur, such as emerald, aquamarine,



GORGE OF NOLICHUCKY RIVER.



VIEW SHOWING EFFECT OF FLOODS ON NOLICHUCKY RIVER.

amethyst, and tourmaline. Some corundum has been found, and there are large deposits of iron ore, notably in the small stream valley of Bumpass Cove, where the iron is mined to supply the furnace at Embreville, which has a capacity of 150 tons of pig iron a day.

DISCHARGE MEASUREMENTS.

During the investigation a temporary gaging station was established on the Nolichucky near Chucky Valley, Tenn., where gage-height readings were maintained and measurements were made as shown in the following table. The river was also gaged near Erwin, Tenn., and numerous miscellaneous measurements were made on its tributaries, as shown by the table on pages 108 and 109.

Discharge measurements of Nolichucky River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
Sept. 5	Near Chucky Valley, Tenn	L. V. Branch and E. W. Myers.	2.0	302
Sept. 20	do	do	2.18	442
Oct. 15	do	do	2.0	378
Nov. 10	do	do	2.9	919
Aug. 23	Near Erwin, Tenn	L. V. Branch	20.67	770
Sept. 4	do	do	21.53	411

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made near Chucky Valley. In making the measurements near Erwin, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

The fall of the river is very much less than would naturally be expected in a stream draining so high and mountainous an area, the total fall between the junction of the North and South Toe and Embreville being only about 850 feet in a distance, following the course of the river, of about 40 miles, an average of about 21 feet to the mile. Throughout this part of its course the river flows through a gorge with steep and rocky sides, and although there are numerous places where dams could be constructed, and although the fall per mile is large, the opportunities for developing the power are meager, for building room is lacking and the construction of raceways would be costly. Good railroad facilities exist here, since an extension of the Ohio River and Charleston Railroad passes along the river bank.

About 1½ miles below the mouth of Caney River, where the stream is about 200 feet wide, there is a fall of 25 feet, or a little more, in a distance of a half mile, but as elsewhere throughout this portion of its course, there is no building room close to the river, though sites could be found near the summits of the hills.

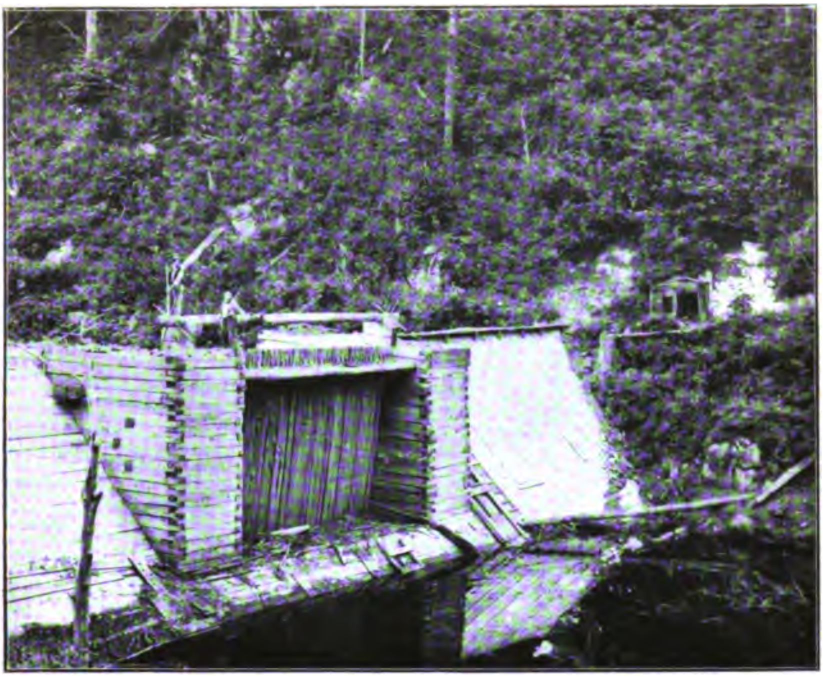
TRIBUTARIES OF NOLICHUCKY RIVER.

DISCHARGE MEASUREMENTS.

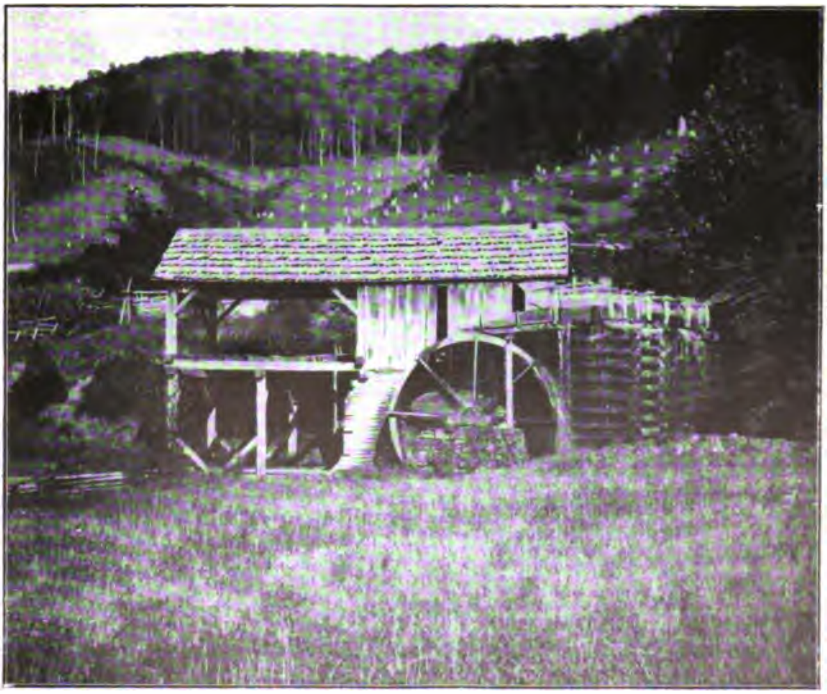
The drainage basins of the principal tributaries of the Nolichucky down to Embreville, Tenn., were visited and the following measurements were made, in order upstream:

Discharge measurements of tributaries of Nolichucky River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Aug. 22	Rock Creek	100 yards above mouth, Tennessee	L. V. Branch	3.69	6.37
Do	North Indian Creek.	Unicoi, Tenn	do	4.58	37.9
Do	do	Erwin, Tenn	do	3.95	51.0
Sept. 4	do	do	do	4.19	22.0
Sept. 19	do	do	E. W. Myers	4.05	29.7
Oct. 16	do	do	L. V. Branch	4.18	28.13
1901.					
June 18	do	do	E. W. Myers		174.0
1900.					
Aug. 23	Martin Creek	Near Erwin, Tenn	L. V. Branch	1.59	7.55
Sept. 4	do	do	do	1.68	6.45
Aug. 23	South Indian Creek.	do	do	5.88	52.3
Sept. 4	do	do	do	5.49	33.2
Sept. 19	do	do	E. W. Myers	5.40	53.0
Aug. 23	Hollow Poplar Creek.	Ford of Erwin-Bakersville road, North Carolina.	L. V. Branch	8.15	5.98
Oct. 16	do	do	do	8.26	2.61
Aug. 24	Toe River	Near Huntdale, N. C	do	15.89	381.0
Oct. 17	do	do	do	16.12	301.0
Aug. 27	North Toe River	At ford of Linville-Cranberry road, North Carolina.	do	3.60	18.0
Do	do	Plumtree, N. C	do	7.55	79.0
July 2	do	Near Sprucepine, N. C	H. A. Pressey		323.0
Aug. 26	do	do	L. V. Branch	18.20	105.0
Oct. 21	do	do	do	18.37	78.0
Oct. 25	do	do	do	17.15	570.0
Aug. 24	Pigeon Roost Creek.	At mouth, North Carolina	do	7.39	14.5
Oct. 19	do	do	do	7.47	4.12
Aug. 24	Big Rock Creek	Ford of Huntdale-Bakersville road, North Carolina.	do	2.42	51.3
Oct. 19	do	do	do	2.64	24.5
Sept. 8	Jack Creek	At mouth, North Carolina	do	6.09	8.71
Oct. 19	do	do	do	6.10	6.83
Sept. 8	Pigeon Creek	do	do	5.86	1.65
Oct. 19	do	do	do	5.85	1.28
Aug. 24	Cane Creek	One-half mile above mouth, North Carolina.	do	9.30	11.75
Oct. 19	do	do	do	9.28	9.93
1901.					
Oct. 21	do	Bakersville, N. C	E. W. Myers		22.82
Oct. 22	do	do	do	0.99	21.05
1900.					
Aug. 25	Brush Creek	Lower ford of Burnsville-Sprucepine road, North Carolina.	L. V. Branch	1.39	4.37
Oct. 20	do	do	do	1.51	0.72
Aug. 25	Crabtree Creek	Ford of Burnsville-Sprucepine road, North Carolina.	do	7.97	15.2
Oct. 20	do	do	do	7.91	14.55
Aug. 25	Snow Creek	Wing, N. C	do	3.08	2.0
Aug. 26	Bear Creek	Flatrock, N. C	do	3.76	4.67
Oct. 20	do	do	do	3.70	3.73
Aug. 26	Grassy Creek	Sprucepine, N. C	do	5.21	6.09
Oct. 20	do	do	do	5.13	9.15
Aug. 26	Beaver Creek	Near Sprucepine, N. C	do	4.50	3.29
Oct. 21	do	do	do	4.29	3.08
Aug. 26	Threemile Creek	Near old post-office at Elsie, N. C.	do	5.38	2.68
Oct. 21	do	do	do	5.30	3.57



A. SPLASH DAM ON LITTLE RIVER, TENNESSEE.



B. COMBINED SAWMILL AND GRISTMILL ON PRICE CREEK, YANCEY COUNTY, N. C.

Discharge measurements of tributaries of Nolichucky River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Aug. 27	Hensons Creek	At mouth, North Carolina	L. V. Branch	6.94	4.8
Do	Plumtree Creek	Plumtree, N. C	do	2.99	8.09
Do	Roaring Creek	At mouth, North Carolina	do	7.89	15.57
Do	Squirrel Creek	One-fourth mile above mouth, North Carolina.	do	3.12	11.2
Aug. 28	Horse Creek	At mouth, North Carolina	E. Graves	5.55	9.03
Oct. 24	do	do	L. V. Branch	5.15	40.53
Aug. 27	Whiteoak Creek	do	do	2.26	3.36
Do	Kentucky Fork of North Toe River.	do	do	2.85	9.7
Aug. 31	South Toe River	One mile above mouth of Three Fork Creek, North Carolina.	do	4.34	26.0
Oct. 26	do	do	do	3.30	101.0
July 1	do	Ford of Micaville-Sprucepine road, North Carolina.	H. A. Pressey		220.8
Aug. 25	do	do	L. V. Branch	8.08	79.8
Aug. 30	do	do	do	7.98	86.23
Oct. 27	do	do	do	7.23	282.9
Aug. 30	Cane Branch	Ford of Micaville-Marion road, North Carolina.	do	3.92	2.98
Oct. 26	do	do	do	3.78	8.59
Aug. 30	Little Crabtree Creek.	Just above lower ford of Micaville-Sprucepine road, North Carolina.	do	4.28	17.54
Oct. 27	do	do	do	4.23	21.67
Aug. 30	Brown Creek	Ford of Micaville-Marion road, North Carolina.	do	3.02	4.94
Oct. 26	do	do	do	2.85	9.43
Aug. 30	Whiteoak Creek	At mouth, North Carolina	do	4.66	4.40
Oct. 26	do	do	do	4.28	19.86
Aug. 30	Locust Creek	do	do	1.98	3.83
Oct. 26	do	do	do	1.87	7.96
Aug. 31	Colbert Creek	Ford of Micaville-Marion road, North Carolina.	do	3.87	2.51
Oct. 26	do	do	do	3.50	7.24
Aug. 31	Middle Creek	do	do	3.94	3.78
Oct. 26	do	do	do	3.64	9.20
Aug. 31	Rock Creek	do	do	1.96	6.92
Oct. 26	do	do	do	1.62	28.68
Aug. 31	Three Fork Creek.	One-fourth mile above mouth, North Carolina.	do	1.49	9.49
Sept. 1	Caney River	Near Big Tom Wilson's, North Carolina.	do	1.33	17.11
Oct. 18	do	do	do	1.34	13.9
Aug. 24	do	Huntdale, N. C	do	3.69	89.9
Sept. 3	do	do	do	3.82	62.77
Oct. 17	do	do	do	3.83	58.3
Sept. 2	Big Creek	At mouth, North Carolina	do	2.83	5.67
Oct. 17	do	do	do	2.89	2.0
Sept. 2	Little Bald Mountain Creek.	do	do	4.91	2.12
Oct. 17	do	do	do	4.90	2.61
Sept. 2	Bald Mountain Creek.	One mile above mouth, North Carolina.	do	3.43	19.7
Oct. 17	do	do	do	3.55	10.6
Sept. 2	Elk Shoal Creek	At mouth, North Carolina	do	1.63	1.29
Do	Bald Creek	Near Burnsville, N. C	do	4.56	16.25
Oct. 18	do	do	do	4.56	9.97
Sept. 2	Price Creek	do	do	2.48	9.46
Oct. 18	do	do	do	2.53	8.85
Sept. 1	Bowlems Creek	do	do	5.03	3.45
Oct. 18	do	do	do	4.97	4.02
Sept. 1	Cattail Branch	do	do	2.78	2.77
Oct. 18	do	do	do	2.64	4.69
Sept. 1	Elk Fork Creek	Near Big Tom Wilson's, North Carolina.	do	1.24	4.78
Oct. 18	do	do	do	1.28	1.49

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Descriptions of the drainage basins and water powers of the larger of these tributary streams are given on the following pages, in order upstream.

NORTH INDIAN CREEK.

Around Erwin, Tenn., and up North Indian Creek there is a very picturesque farming country. The creek drains a large area, the upper part of which is mountainous, with steep slopes, while near the Nolichucky it broadens out into a fertile valley. The low-water discharge was measured and found to be 22 second-feet. On this creek, at Unicoi, Tenn., the Unaka Milling and Lumber Company has a large wood-working plant and gristmill. Their power (about 40 horsepower) is developed by 20-inch and 24-inch turbines working under a head of 16 feet. Just above Unicoi an old ore washer formerly utilized a fall of 30 feet, but it is now out of use. On Dick Creek, a tributary of North Indian Creek, there are four falls averaging 30 to 40 feet each. In the limestone cove on North Indian Creek there are four gristmills using the water power. This cove is a widening of the valley of the creek, and in it are a number of good farms under cultivation. Much limestone is found over this entire section of country. Two miles above Erwin, on the Nolichucky, J. T. Wilder has a sawmill and woodworking plant. The dam across the stream is 17 feet high and backs the water in the river three-fourths of a mile. About 80 horsepower is developed by one turbine.

SOUTH INDIAN CREEK.

Entering the river from the south, about 2 miles above Erwin, is South Indian Creek, a stream in many respects similar to North Indian Creek, though the proportion of cleared land in its basin is somewhat less.

The creek rises on the northern slope of the Unaka Mountains, draining an area the upper part of which is made up of high, steep, and rugged mountain slopes, which as a rule are very densely forested. As the stream is descended, however, the mountains recede from it and leave broad and fertile bottoms, which are entirely cleared and under cultivation, grass, corn, and wheat being the principal crops. The cleared areas form a very small part of the whole basin, however, probably less than 10 per cent.

A great deal of timber is being cut in this area, particularly near the heads of the smaller tributaries near its mouth, and there are several small sawmills located on the creek which cut part of this product, the remainder being worked upon the spot by the small portable sawmills which are moved from place to place as the timber is cut.

At the time the stream was visited in September, 1900, its discharge was very low—about 33 second-feet. It is said to have reached a lower stage during the summer and fall of that year than ever before. The flood rise at the mouth is between 7 and 8 feet.

HOLLOW POPLAR CREEK.

This stream, which receives its drainage from the eastern slope of the Unaka Mountains, has a low-water flow of about 6 second-feet. Excepting the lower 2 miles, where there are several small farms, the creek valley is very narrow, with almost no land under cultivation. The side hills are steep and are heavily covered with timber and underbrush. The slope is greater than that of either North Indian Creek or South Indian Creek, the total fall from source to mouth, a distance of 5 miles, being about 2,000 feet. The fall is greatest near the headwaters, where it is a mountain stream jumping from ledge to ledge down the side of the mountain. There is no cleared land except near its mouth, the steep slopes being covered with the original forest growth.

NORTH TOE RIVER.

The North Toe rises on the western slope of the Blue Ridge, in the northeastern part of Mitchell County. Its course is circuitous, flowing first to the southwest, then to the west, and then to the northwest, receiving numerous tributaries, the chief of which is the South Toe, which unites with it on the line between Mitchell and Yancey counties. Practically the whole of Mitchell County is drained by the North Toe and its tributaries, the Nolichucky proper receiving the drainage from the extreme western part of the county, a small part of the northeastern section draining into Elk Creek, a tributary of the Watauga, and another small portion of the eastern section being drained by Linville River.

The region of the headwaters of the North Toe is very rough, with steep mountain slopes and narrow valleys sparsely populated. Along Whiteoak Creek and for a distance on the main stream and the Kentucky Fork above their junction the valley is wide and flat, but is heavily timbered. Part of it is in a rather swampy condition and is covered with heavy laurel thickets. Below the mouth of Whiteoak Creek the mountains close in and form a narrow and steep gorge as far down as Horse Creek. There the valley widens out a little, and from there down there is some bottom land under cultivation on each side of the river.

The tributaries of the river in this section and as far down as Sprucepine flow directly from the mountains in narrow gorges. They are for the most part short streams with great fall but with little water. The only cleared land along them is within a half mile of their mouths or on top of the mountains from which they flow, the mountain sides being too steep for successful cultivation. Throughout the region from the head of the river and its tributaries down to Sprucepine and to the mountain summits on either side probably not more than one-sixth of the land is cleared. The cleared areas are nearly all planted in wheat and corn, although a small portion is in grass, for grazing purposes. A few miles above Sprucepine the mountains recede from the river, leaving a very wide valley, which extends down to the Cane Creek Valley on the north side of the river and to Caney River on the south side. This valley is rather hilly throughout most of its area, and the land is cleared on the north side between Sprucepine and Bakersville. On the south side most of the cleared land is around Burnsville, although there are a number of farms near Sprucepine and along Grassy Creek.

One mile above the mouth of Pigeon Roost Creek and just above the ford there is a very good site for the construction of a dam. A water power of considerable magnitude could be developed here. Lying to the south of the main channel of the river is an island which rises about 15 feet above the water level and is never overflowed, not even during the highest floods. There is a heavy fall in the river, and by the construction of a dam from the end of the island to the north bank of the stream all of the water could be turned into the narrow channel behind the island and a fall of 15 feet or more be obtained.

Above this point there are many shoals, the river having a large fall throughout that part of its course, flowing in a deep gorge, with sides rising at angles of 30 to 40 degrees. There are several small mills on the upper part of the river, but the larger portion of the power developed in the basin is derived from the tributaries, the needs of the mills requiring the development of only a few horsepower at any place. Powers of considerable magnitude, however, can be developed on these streams, for notwithstanding the amount of water carried by each one is small the fall obtainable in a short distance is large, and absolutely safe locations for buildings can be obtained, which is not always the case on the main river.

The first mill of any size on the North Toe is just above the mouth of Bear Creek. It is a gristmill, mica-grinding mill, and wood-carving establishment. The owners have developed a 6-foot fall and claim to have about 75 horsepower. At Elsie, farther upstream, there is a combined flour mill, sawmill, and gristmill with a small dam giving a 10-foot fall.

Just below the mouth of Plumtree Creek Vance Brothers have a combined mica mill and sawmill, using a large part of the low-water flow in the river with a 36-inch Samson turbine under an 11-foot head. Mica is abundant throughout this district, and is mined extensively from Plumtree Creek down the river as far as Big Rock Creek on the north and Caney River on the south. In this district there are also several water powers developed for grinding mica.

The swift-flowing tributary streams of the North Toe, with their numerous vertical falls, furnish abundant power for small mills, and a number of the power sites have been developed, though in a small way.

On Pigeon Roost Creek, which enters Toe River 2 miles above the mouth of Caney River and has a low-water flow of about 14½ second-feet, there are two large mills, the first a small sawmill and gristmill about 100 yards above its mouth, utilizing a fall of 16 feet; the second one a sawmill and gristmill 3 miles upstream, using an overshot wheel.

There are only two rolling mills in Mitchell County—one on Big Rock Creek, belonging to Henry Master and having a capacity of 30 barrels per day; the other on Cane Creek, just below Bakersville, and having about the same capacity. At Magnetic, on Big Rock Creek, there is a large mica mill, and at the mouth of Beams Creek is located Garland's mica mill, using a 15½-inch Leffel wheel. On Cane Creek there is a sawmill just above its mouth, and at Wing, on Snow Creek, J. C. Phillips has a sawmill and gristmill using two overshot wheels of 14 and 15 feet diameter, respectively. Above this mill there are two small gristmills on Snow Creek.

On Crabtree Creek, 4 miles above the mouth, there is a fall of 100 feet, 40 feet of which is in a clear vertical leap. Six mica mills, run by one turbine under 116 feet head, are located at this place. On Bear Creek there are two small corn mills with a fall of 20 feet and 12 feet, respectively. On Beaver Creek there is a combined sawmill and corn and wheat mill run by an overshot wheel and a Leffel turbine with an 18-foot fall. Farther up the stream there is a small corn mill run by a 16-foot overshot wheel.

On Hensons Creek (marked Powdermill Creek on atlas sheet—an obvious error, for Powdermill Creek is the unnamed tributary just above it) there are three mills. The lower one is a small gristmill run by a tub wheel. Above this is Houston's sawmill, gristmill, and planing mill, run by a Leffel wheel under a 35-foot head. The upper mill, Green's sawmill, has an overshot wheel and 23 feet fall. On Plumtree Creek there is a mill, run by using the 12-foot fall on a turbine wheel, making pins for telegraph wires. One mile above, on the same creek, there is a mica mill using 91 feet fall on a turbine. Still higher up on Plumtree Creek there are four small corn mills. Powdermill Creek, Hensons Creek, Roaring Creek, and Squirrel Creek, running down the sides of the mountain, have almost unlimited falls but little water. The discharge of these streams at their lowest stages is as follows: Hensons Creek, 4.8 second-feet; Powdermill Creek, barely 1 second-foot; Roaring Creek, 16 second-feet; and Squirrel Creek, 11 second-feet.

By far the largest tributary of the North Toe is Big Rock Creek, which with its tributary Little Rock Creek rises on the southern slope of the Iron Mountains, which form the dividing line between Tennessee and North Carolina. They receive a large part of the drainage from those high and rugged mountains, the culminating peak of which is Roan High Knob, with an elevation of 6,313 feet. Cloudland, a noted summer resort on this peak, affords one of the finest views obtainable from any of the summits of the Appalachian Mountains. Here is a very comfortable summer hotel, pure water, cool climate, and all that goes to make a pleasant and healthful summer resort. A narrow-gage railroad passes through Roan Mountain Station, 12 miles from Roan High Knob, from which point a good road has been built up the mountain side. When on Roan Mountain the Black Mountains, Hawks Bill, Table Rock (on Linville River), and the mountains of Virginia and Tennessee are in full view. One can but wonder why more is not known of these mountains and why the visitors are so few. It is, however, probably a matter of only a few years before this region will be one of the great mountain resorts of the country.

SOUTH TOE RIVER.

This river rises in the southern part of Yancey County, N. C., and flows directly north into the North Toe. It receives its drainage from the eastern slope of the Black Mountains and the western slope of Sevenmile Ridge. It follows close to the base of the latter ridge, which rises abruptly from the water's edge. On the west side of the stream the steeper slopes of the Black Mountains are about 2 miles from the river, leaving a narrow valley between. There are, however, no farms on either side of the stream, and even in the narrow valley on the west side only a few tracts (hardly one-fifth of the area) have been cleared for cultivation. Considering the drainage basin from the river to the mountain summits on both sides, probably not 1 per cent of the land has been cleared. About 2 miles above the mouth of the river the mountains on both sides recede, leaving the land from that point to the North Toe level compared with the rest of the region, although it is still a very hilly country.

Little Crabtree Creek, with a minimum discharge of 18 second-feet, is the largest tributary of the South Toe. It rises near Burnsville, in the foothills of the mountains, and joins the river a short distance northeast of Micaville. The river has seven other small tributaries, ranging in size from 2.5 to 9.5 second-feet at their lowest mid-summer flow.

There is not a mill on the South Toe, and only one or two small corn mills on its tributaries. The steep watershed and the short tributaries carry the rainfall quickly to the main stream, causing rapid fluctuations and high floods, making mill improvements difficult and expensive. This probably accounts for the few power developments in the watershed.

CANEY RIVER.

This river also rises in the southern part of Yancey County and flows northward uniting with Toe River to form the Nolichucky. It receives its drainage from the western slopes of the Black Mountains and the eastern slopes of the Bald Mountains, and has a minimum discharge of about 63 second-feet from a drainage area of about 158 square miles. The western slopes of the Black Mountains are similar to the eastern slopes, which are drained by the South Toe, being steep and heavily wooded, the forest growth changing from the foot to near the top, where little except balsam is able to stand the low temperature. Near the foot of the mountains large areas are covered with heavy laurel thickets.

Unlike the South Toe, most of the cleared land along Caney River is in its upper and middle portions, while along its lower course the stream flows through a valley so narrow that it may be considered almost a gorge. The valley above Burnsville, however, is wider than that of the South Toe and has a larger percentage of cleared land. One mile below Burnsville the river enters a narrow gorge through which it runs for about 3 miles, but even here the higher lands are largely cleared. Farther down, the country is flat and well cleared for 6 or 7 miles; then the river enters the narrow gorgelike valley through which it flows, with many twists and turns, around the mountain knobs to its mouth. In this gorge there are very few places wide enough for clearing, but on the mountain sides the land is cleared except in the steepest parts. During the last summer (1900) the Ohio River and Charleston Railroad was extended up Nolichucky River as far as the mouth of Caney River, and since that time much lumbering has been done in this section, as already mentioned. Of the area drained by Caney River perhaps one-fourth is cleared. Fully one-half of the valley land is cleared and is largely under cultivation. Wheat and corn are the principal crops. Near the head of the valley lives Big Tom Wilson, one of the earliest settlers in this region and the man who found Professor Mitchell after his ill-fated expedition and untimely death.

The only tributaries of Caney River of any size are Bald Creek, which has a low-water flow of 16 second-feet, and Bald Mountain Creek, which has a low-water flow of 20 second-feet. There are other smaller tributaries, ranging in their low-water discharge between 1.3 and 9.5 second-feet.

Only one water power on Caney River has been developed, and this by a small gristmill located about halfway between Burnsville and the mouth of the river. A large tract of land at the headwaters, including the northwestern slope of Mount Mitchell, is owned by Colonel Murchison, of New York, who holds it as a game preserve.

FRENCH BROAD RIVER.

GENERAL FEATURES.

French Broad River rises on the eastern slope of the Tennessee Ridge, between Jackson and Transylvania counties, N. C., flows in a general northeasterly direction across Transylvania and Henderson counties, a distance of about 30 miles, then northward across Buncombe County, a distance of more than 20 miles, then northwesterly across Madison County, a distance of 20 miles, through the Great Smoky Mountains and into eastern Tennessee, where it is joined by the Nolichucky and the Holston, and finally enters Tennessee River, its waters eventually reaching the Mississippi and the Gulf of Mexico. For convenience the drainage basin has been divided into two parts: (1) The area drained by the river in North Carolina, and (2) the area drained by it in Tennessee.

WATERSHED IN NORTH CAROLINA.

The portion of the drainage basin of French Broad River in North Carolina is comprised within the limits of Transylvania, Henderson, Buncombe, and Madison counties. The small streams from the mountains in the upper part of the watershed soon reach the wide plateau and unite into a broad and sluggish river, with practically no shoals or falls. Little clearing has been done on the upper watershed, but an extension of the Transylvania Railroad has just been completed as far as Jeptha, for the purpose of transporting lumber. The terminus of this extension is called Toxaway. The larger part of the land around the headwaters of the main stream as far as the North Fork is owned by the Toxaway Company, and they expect very soon to commence extensive lumbering operations.

Through all of this region springs are numerous, and the water is pure and cold. Above Jeptha there is very little pasture land, but the region appears to be well adapted to grazing. The mountains around the head of the North Fork are high, many of them reaching an elevation of 6,000 feet. They are traversed by trails only, the forests being still in a wild condition and the region but sparsely populated. The watershed of the North Fork as a whole is not thickly wooded, but no timber cutting has been going on for a long time. Most of the land east of this stream, including the large area of Pisgah Ridge, is owned by Mr. George W. Vanderbilt and is under the care of an expert forester. Above Jeptha the mountains close in to the banks of the stream, and consequently the branches are short and the slopes steep. Between the mouth of Tucker and Shoal creeks, on the North Fork, are some excellent shoals, but no suitable locations for large buildings, although there are shelves of rock on each bank throughout the entire distance. The fall here is about 30 feet in 200, consisting of three drops about 100 yards apart, with rapids intervening. The water power has not yet been utilized.

The drainage area of the river above Asheville is 987 square miles; the total drainage area in North Carolina 1,745 square miles. Of this total area at the time the Tenth Census was taken 1,091,000 acres were under cultivation and 8,079,000 acres, or 78 per cent of the whole, were still forest covered. In 1890, according to information gathered for the Eleventh Census, about 30 per cent of the area was cultivated land, and as the rate of clearing has been accelerated during the last decade, on account of the large development of the lumber industries, it seems safe to conclude that at the present time about 40 per cent of the whole area is either cultivated land or land from which the timber has been removed.

Transylvania County, in which are the headwaters of the river, is a true mountain region, having on its southern boundary the Blue Ridge in its most massive and imposing form, and being the starting point of the great Pisgah and Balsam ranges, which stretch through the county toward the north. The only exceptions to the rugged topography are the broad and fertile valleys of the French Broad and its tributaries, which are cultivated and in a high state of improvement, being among the most valuable and productive farming lands in the State. These valleys are the scene of an important stock-raising industry, which is the principal source of revenue, though enormous crops of cereals and grasses are produced, some tobacco is raised, and fruits of large size and fine flavor are grown. The greater part of the county is still in the original forest growth of the usual varieties found in these mountains, which attain great size on account of the surpassing fertility of the soil. There are extensive areas of white-pine timber which will yield fairly good lumber. The merchantable trees of walnut and cherry have been largely removed, though an occasional walnut of fair size is seen, and small tracts of cherry are said to exist on the higher mountain slopes. Large tracts of poplar are also to be found, and but little oak has been cut. It is estimated that of the total area of the county only about 15 per cent is cleared land.

There has been no development whatever of the mineral wealth of Transylvania County, though gold, silver, lead, copper, nickel, asbestos, corundum, and mica are said to exist in the vast wilderness of the Balsam and the Pisgah mountains.

Henderson County is the northward or downstream continuation of the valley of the French Broad, and its topographic features are similar to those of Transylvania County, except that its areas of comparatively level and fertile land are larger and the general aspect of the country is less mountainous. A remarkable feature is the apparent great depression of the surface and the width of the stream valleys, some of which assume, as on Mud Creek, the character of a wide swamp. This depression is, however, apparent and not real, the most depressed portions being above the level of the Blue Ridge plateau. The hillside slopes are very gentle.

The soil on the uplands is not remarkably fertile, being a light-gray gravelly or sandy loam. The soil in the valleys is in large part alluvial, with much vegetable matter, and yields large crops of grains, grasses, vegetables, and fruits. Corn grows well, especially in the valleys, but the principal agricultural industry is the production of cabbages and other vegetables for market. A great deal of fruit is also grown, and is either canned or dried.

Along the stream valleys of Henderson County pine is the predominant growth, but on the uplands oak, chestnut, hemlock, and pine are to be found, while near the summit of the mountains and in the cold and sheltered coves walnut, cherry, maple, and an occasional white pine are seen. The lumber industry, however, is of small importance, though some logs have been floated to Asheville, and small amounts of timber are cut annually for local uses. Some tan bark is also gathered.

Although the proportion of comparatively level land in this county is very great, a smaller proportion of the area is cleared than in either Madison County or Buncombe County, the cleared land amounting to about 31 per cent of the whole, according to the returns of the Eleventh Census, and only small amounts of clearing have been done since that time, so that it is improbable that the cleared land now amounts to more than 35 per cent of the entire area.

The country rock throughout Henderson County is for the most part a gneiss, but the valley of Boylston Creek is in a schistose limestone of a gray-blue color, which in places carries thin veins of quartz. The mineral wealth of the county is greater than that of either Madison County or Buncombe County. What is said to be the largest deposit of zircon in the United States occurs in the valley of Green River, and gold is found at the Boylston mine, on the southeastern slope of Forge Mountain, 13 miles west of Hendersonville.

The general surface of Buncombe County, the next county to the north, is more hilly than mountainous, with stream valleys narrow and limited in extent, which, however, offer good facilities for agricultural operations. Between Asheville and Alexander the country on the north side of the river as far as could be seen was gently rolling, with slopes of from 5 to 15 degrees, about two-thirds cleared and largely cultivated in grass. On the south side of the stream the country preserves the same general character, but the hillside slopes appear gentler, averaging between 5 and 10 degrees, about the same proportion of land being cleared. The forest growth, which for several miles back from the stream is in small segregated areas—too small to affect the run-off—is more largely pine than in the basins heretofore described. A number of tributaries rising in the gaps of the mountains enter the main stream, adding much to the beauty of the scenery. Every year great numbers of tourists visit the valley of the French Broad in search of health or pleasure. Pl. XXX is a view on Swannanoa River, one of the favorite streams of nature-loving tourists.

The upland soils in Buncombe County are stiff, even-grained loams, rarely sandy, generally deep, being derived from the disintegration *in situ* of gneiss, and are on the whole very fertile. The soils on the lowlands are rich sedimentary loams, with much vegetable matter

SWANNANOA RAPIDS ON SWANNANOA RIVER, NORTH CAROLINA.

along the smaller streams. Along the larger streams are loams similar in character to those on the smaller streams, but more sandy and less fertile. The hills erode rapidly when unprotected, but are generally quickly seeded with grass, producing a retentive turf.

The soils produce all of the cereals, grasses, and fruits, wheat yielding 10 or more bushels to the acre. Oats do well. Corn thrives, producing from 30 to 40 bushels to the acre, while clover and the grasses yield fine crops of hay. In recent years more and more attention has been paid to the raising of beef cattle for market, and this is now an important industry throughout the county. Many chickens and turkeys are also raised, these selling for good prices. Of the fruits, apples are produced in greater abundance than any other, and they are of large size and fine flavor. All vegetables grow well, the cabbages being particularly good. Tobacco is largely cultivated along the river and on the hills a few miles back from it, these localities seeming best adapted to its production. A good grade of bright tobacco is obtained.

The timber in Buncombe County includes all of the varieties found in the mountains—oak, hickory, walnut, beech, birch, chestnut, locust, pine, spruce, and others, with a dense undergrowth of dogwood, laurel, azalea, and other shrubs. There are large mills sawing lumber at Asheville and many small ones in close proximity to the timber. A considerable quantity of tan bark is also shipped from the county, the oak stocks being generally sold for fuel after being barked, but as a rule no use is made of the hemlock stocks. Walnut, curly birch, and curly ash are shipped in the log to veneering factories, but the merchantable trees of this class have been largely removed, and poplar and cucumber trees, which furnish the chief building materials of the region, are also becoming scarce. Timber that can be floated, such as pine, poplar, and chestnut, has been largely removed to supply the mills at Asheville, but little oak has been cut. According to the returns of the Eleventh Census, about 25 per cent of the area of the county was at that time cleared land. Since then, however, much clearing has been done, so that it is estimated that at the present time 40 per cent of the area is cleared; some estimates place the amount of cleared land at 50 per cent, and it is generally stated that about two-thirds of the cultivable land is cleared. Mr. George W. Vanderbilt is the largest owner of forest lands in the county. He owns many thousand acres to the south and east of Asheville, and modern scientific methods of forest management have been inaugurated in all forests owned by him.

As has previously been stated, the country rock of Buncombe County is principally a gneiss, though there are areas of granite, and across the southern edge of the county there is a narrow belt of slates and schists. The mining industry is unimportant. Talc is met with occasionally, nickel is seen in very small quantities, and a serpentine of good quality occurs in abundance between Weaverville and Leicester, but the vein has never been worked. Magnetic iron ore has also been found at several places. It is said that many years ago some of the latter veins were worked; and a deposit has recently been opened at the Blackwell mine, near Blackwell Springs. Limonite is found in many places throughout the county, and brick clay is abundant. The latter is made into common and pressed brick at several yards, some fire brick is made, and a plant at Biltmore formerly manufactured drain and roofing tile and paving brick.

Mineral springs of divers kinds are abundant, those carrying sulphur being the most noted. There are also numerous nonmineral springs, which furnish large amounts of water to the streams.

The country roads furnish the chief means of transportation throughout the county, and while there has been a movement for good roads, particularly in the region near Asheville, the greater portion of the country roads are poorly graded and become almost impassable in the winter, on account of mud.

Madison County, the next county through which the French Broad flows, is also essentially a mountain country, there being very little valley land and the whole area being traversed by mountain ridges ranging in height from 2,500 feet to 4,500 feet above sea level. None of the ranges, however, rise to so great heights in this county as they attain in the adjoining counties, even the Great Smokies being below their average elevation. The soil is very fertile and produces fine crops, though from the almost entire absence of transportation facilities the agricultural products are limited to little more than enough to supply the inhabitants, a very small amount being raised for market. The hills are especially adapted to the production of a good grade of bright tobacco, large quantities of which were formerly grown and marketed in Marshall or Asheville, but recently, on account of the low prices obtained, this industry has suffered a diminution, and the "deadening," as the exhausted tobacco fields are known locally, are to be seen on many hillsides, either uncultivated or growing corn or other grain. Stock raising produces a large annual revenue, which could be considerably increased.

The mineral wealth of the county is known to be large, but it is mostly undeveloped. Magnetic iron ore, chromic iron ore, manganese, nickel in small quantities, corundum, serpentine, talc, and baryta are all found. Some corundum has been mined and shipped, much baryta has already been taken out and is still being mined by many individual miners. Recently a talc mine has been opened near Stackhouse, which is said to produce a very good quality of that mineral.

The timber found throughout Madison County is remarkably fine. Walnut trees 8 feet in diameter, poplars 10 feet in diameter, wild cherry, black birch, and buckeyes 3 or 4 feet in diameter are met with occasionally, while the common timber trees, such as oak, chestnut, and pine, are plentiful and of large size. Much timber has already been taken out and much is still being logged wherever the crude

FRENCH BROAD RIVER AT PAINT ROCK, N. C.

methods of lumbering prevalent can reach it. There are large mills at Stackhouse and at Putnam, and small portable mills are located wherever the timber can profitably be attacked, the lumber being wagoned to the railroad for shipment.

The geologic formations of the county are similar to those of Cocke County, Tenn. Close to the State line there is a belt of sandstone, which is succeeded by slates and schists. About a mile below Hot Springs the latter give place to limestone and dolomite, which above the springs are succeeded by sandstones, slates, and schists, and these in turn by the gneisses and granite which are the predominant rocks of the county.

The Hot Springs mentioned as being located in the limestone belt constitute one of the most interesting features of the region. They are 6 or 7 miles above the Tennessee line, directly on the banks of the river, some springs indeed bubbling up in the bed of the stream. As the name indicates, the water is warm, although of varying degrees of temperature, and possesses many valuable medicinal properties, said to be particularly efficacious in rheumatic cases. There is a large hotel at the springs, and many people come to take the hot baths, for which the waters are chiefly used.

Throughout its course in Madison County the river flows in a deep gorge which it has carved out in the gneisses and slates, now twining among the hills and now cutting through them, leaving at the latter places almost perpendicular walls of bare rock several hundred feet high or slopes of from 50 to 60 degrees covered with a sparse growth of gnarled and stunted trees clinging to the interstices of the rock.

Pl. XXXI is a view of the river at Paint Rock, near the North Carolina-Tennessee boundary, and shows both the forested slopes and the perpendicular rock walls in this portion of its course. As the river is ascended the sides of the gorge become gradually lower and less steep, and the country beyond the crests of the river bluffs loses somewhat its mountainous character, becoming instead a region made up of rounded hills and swells, with broader and more nearly level valleys between, a much larger proportion of the land being cleared, the cleared areas increasing from practically none on the extreme northern, western, and southwestern borders to probably 50 per cent of the area above the mouths of Walnut and Pawpaw creeks.

Throughout this area none of the closed basins which have been so notable a feature in some other areas were noted, but instead there seems to be a greater number of small stream channels, most of them carrying some water, which was not the case over a large part of the area drained by the South Fork of the Holston.

WATERSHED IN TENNESSEE.

The part of the drainage basin of the French Broad which is situated to the east of the town of Newport, Tenn., the western limit of the investigation, is comprised entirely within the limits of Cocke

County. The area immediately about Newport and for 5 or 6 miles to the east while hilly is not mountainous, and in many respects bears a close resemblance to the country seen along the South and Middle forks of Holston River, consisting, as it does, of rather low hills and broad ridges of gentle slopes largely cleared and grass covered. In parts of this area, particularly in the part seen from the road leading from Parrottsville to Newport, numerous small closed drainage basins or sinks were observed, many of them of large size and having pools of water in their bottoms. Occasionally, over an area of a square mile or more, these sinks occur in such numbers as to absorb the entire drainage, permitting, so far as could be observed, no water to find its way into the stream channels. This will tend to produce complications when the run-off from two similarly situated areas is compared if either area contains basins. None of the basins were noted above the North Carolina line. There are numerous springs of chalybeate and sulphur water in Cocke County, and large numbers of springs whose waters possess no medicinal properties.

It is along this part of the course of the stream that the far-famed scenery of the French Broad occurs, but with all its beauty the scenery barely equals that seen when the summit of the river bluffs has been reached, where vistas of mountain and meadow, woodland and stream are spread out before the eye, scenery of which the rugged beauty of that along the river has given no promise.

If the whole area of Cocke County be considered, about 40 per cent of the land is cleared and cultivated, according to the best information obtainable; but this includes a part of the vast Unaka mountain chain, with its outlying spurs and ridges, where the proportion of cleared land is exceedingly small, so that it is estimated that from 65 to 70 per cent of the area to the west of the mountains is cleared and under cultivation or in grass, which is one of the principal products.

The mountains rise very abruptly and steeply from the more level area, and the proportion of cultivable land on them is small, being confined to the stream valleys and to a few of the lower and gentler slopes. In some of the coves and gorges the soil is productive, but these areas are too small to be of value for grain growing. They are, however, adapted to the production of grass and fruit, although very little has been done in that direction. The principal valley is of course that of the main stream, which has an average width of about 1 mile and is exceedingly fertile, the soil, which is alluvial, being deep and producing, with good cultivation, from 50 to 100 bushels of corn to the acre, this being the principal crop. Oats thrive very well, wheat not so well. Of late years more of the land has been sown to grass, and the stock-raising industry now affords a considerable revenue to the people of the county. The price of land ranges from $1 and $2 to more than $50 an acre.

There is some very fine timber in Cocke County, mainly oaks of various kinds, chestnut, maple, hickory, walnut, white and yellow pine, spruce, and other varieties. Formerly a great many shingles were made, mostly from white pine. A limited amount of lumber is sawed annually by the small country mills for local uses, and a much larger amount of timber is annually destroyed for the purpose of stripping tan bark or for railroad ties; but taken as a whole the timber industry is of little importance, and the same is true of manufactures in general. There is a small cotton mill at Newport, also one or two small sawmills and a flouring mill, and there are small sawmills and gristmills at various places in the county, but they are of little importance.

The mineral wealth in this section is very great, but so far as could be learned nothing has been done toward developing it. Iron is said to occur in paying quantity, also lead and baryta. Newport is just at the junction of the shales and the limestone, which there form a narrow valley, and for 5 or 6 miles up the river limestone and dolomite occur, the prevailing color being blue, though layers of gray rock are also found. The limestone and dolomite are succeeded by red shales, and these, for a fourth of a mile or more upstream, by white or grayish sandstones. Passing these sandstones, shales or slates are again met with, bands of conglomerate occurring at intervals, also a few layers of dolomite. The sandstone then makes its appearance again and continues several miles up the river, or to and beyond Paint Rock.

RAINFALL.

The total annual rainfall at Asheville is 42.6 inches, distributed as follows: Spring, 11.7 inches; summer, 13.8 inches; autumn, 7.7 inches; and winter, 9.4 inches. Asheville, however, is in a region of rather low precipitation compared with the rest of the mountain country, although the records of the station at Waynesville show that the annual precipitation between Asheville and Paint Rock is very near the amount stated. Records of stations above Asheville show that the annual rainfall increases very rapidly as the stream is ascended, and near the headwaters, but across the divide, are stations having a mean annual precipitation of between 72 and 73 inches, with an occasional record of more than 105 inches.

The distribution of the rainfall is favorable to a large annual run-off in the stream, since at the time when plant life and evaporation make the heaviest demands upon the precipitation the rainfall is greatest, and it is least in autumn and winter, when these demands are at a minimum. However, since the autumn precipitation is the least and plant life and evaporation are still rather active, the stream is then subject to periods of low flow, although the run-off per square mile is large when compared with streams draining areas out of the mountains, and remains so during even the periods of severe drought.

TRANSPORTATION.

Throughout the greater part of the basin of the French Broad the transportation facilities are poor, being mainly confined to the ordinary country roads, which as a rule are steep and rough, poorly graded and ill kept. The Knoxville branch of the Southern Railway follows the course of the stream very closely below Asheville, and the Spartanburg branch of the same system runs approximately parallel to it for a long distance in the upper part of its course, while the Murphy branch furnishes railroad facilities for the inhabitants of the valley of Hominy Creek. The Hendersonville and Brevard Railroad has recently been constructed from Hendersonville to Jeptha, in Transylvania County, furnishing an outlet for the products of the upper part of the basin. But owing to the character of the country the transportation facilities are less effective than they otherwise would be, and there seems no present prospect that the conditions will be bettered, though one or more additional lines of railroad have been projected to traverse the basin. On the whole, however, the transportation facilities of the area are better than those of any other section of western North Carolina, and in consequence it is better known to the outside world and is more prosperous than the areas to the northeast and the southwest.

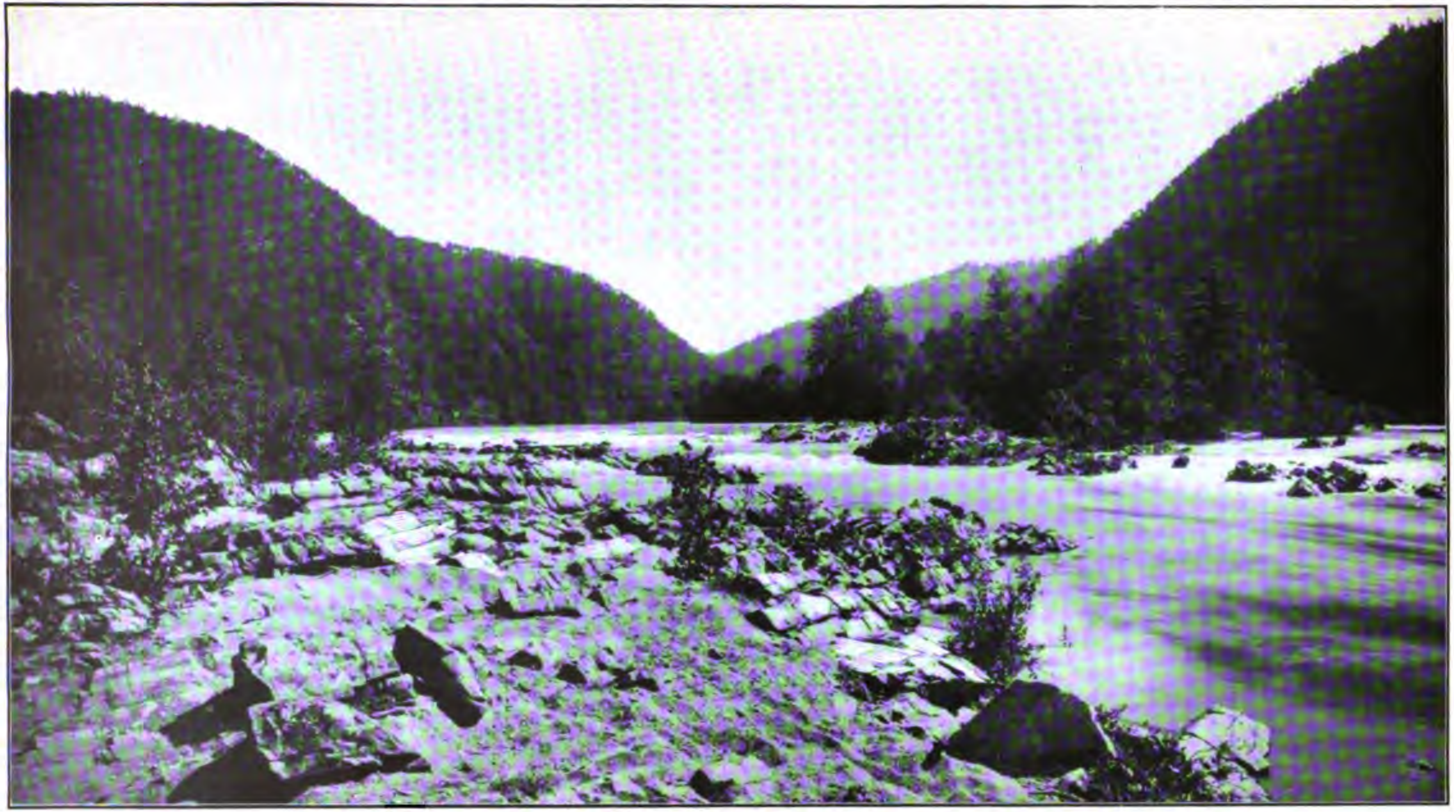
DISCHARGE MEASUREMENTS.

During the investigation a gaging station was established on the French Broad at Oldtown, Tenn., where measurements were made from time to time, also at other places along its course, as shown in the following table. The Survey has maintained a gaging station at Asheville since September, 1895, the results of which have been published in the annual reports.

Discharge measurements of French Broad River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
Sept. 4	Oldtown, Tenn	E. W. Myers and L. V. Branch.	1.00	867.0
Nov. 2	.....do	.....do	1.28	1,653.0
Dec. 15	.....do	.....do	1.30	1,976.0
Dec. 26	.....do	.....do	....	2,901.0
Sept. 7	One-half mile above Hot Springs, N. C.	L. V. Branch	19.35	938.0
Sept. 12	Alexander, N. C	E. W. Myers	17.15	840.0
Oct. 29	.....do	L. V. Branch	16.27	2,068.0
Sept. 18	Fanning Bridge, North Carolina	N. C. Curtis	16.22	1,161.0
Oct. 17	.....do	.....do	16.95	614.0
Sept. 17	Penrose, N. C	.....do	19.80	1,160.0
Sept. 13	Near Carson Creek, N. C	.....do	13.80	266.5
Oct. 15	.....do	.....do	13.90	206.5
Sept. 14	Eastatoe Bridge, North Carolina	.....do	12.40	113.0
Oct. 15	.....do	.....do	11.21	102.4

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table at Oldtown. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.



MOUNTAIN ISLAND SHOAL, FRENCH BROAD RIVER, NORTH CAROLINA.

WATER POWERS.

In describing the fall and power of the French Broad we will start near Newport, Tenn., and follow upstream to its source. At the starting point, about 2 miles north of Newport, the river is a comparatively placid stream, flowing between willow-bordered banks and through broad and fertile grass-covered bottom lands, and this character is preserved for 5 or 6 miles, when there is an abrupt descent of about 4 feet over a rock ledge extending straight across the stream. Near these falls the bottom lands almost entirely disappear and the mountains begin to close in on the river, the hillside slopes, which are sparsely forested, varying from 30 to 50 degrees. Farther upstream an occasional broad bottom is to be seen, but the mountains continue to rise higher and higher as the stream is ascended, the river entering a gorge which reaches a very highly developed stage near Paint Rock. (See Pl. XXXI.) Throughout this distance, however, there is little concentration of fall in the stream, the fall averaging about 10 feet to the mile, following the course of the river, which is very tortuous in this section.

The stream preserves the same general character as far as Hot Springs, the average fall per mile between Paint Rock and Hot Springs being about the same as in the section between Paint Rock and Newport. Above Hot Springs, however, the character of the river changes abruptly, and from a smooth though rapid stream it becomes a tumultuous mountain torrent, dashing along among many huge bowlders and over the rock ledges which obstruct its course and project above the surface in jagged ridges, twining and curving around the hills between lofty and steep walls of rock, which are thinly clad with stunted trees. The river contains many islands and is in places very wide.

In the 7.7 miles between Hot Springs and the mouth of Brush Creek the total fall is 201 feet, giving an average fall of 26.1 feet per mile. There are several places in this distance where the fall is noticeably concentrated. The first of these is about one-fourth of a mile above Hot Springs and is known as the Mountain Island Shoal. At this shoal, shown in Pl. XXXII, a high and rocky island about 200 yards long divides the stream into two parts. The most noticeable concentration of fall is at the ends of the island, there being at the lower end an almost vertical plunge of between 4 and 5 feet, and at the upper end two plunges of about 3 feet each. There is also a fall of about 4 feet in the distance between these plunges, making a total fall of about 15 feet at this place. Below the island the river contracts suddenly to a width of about 100 feet and the water is very deep and sluggish. The railroad is on the north bank, crossing the stream a short distance below the island, and as the track is only a few feet above the level of high water, it offers an obstacle to the development of the power. A development could be made, howev but at considerable expense, by constructing a wing dam from t upper end of the island diagonally toward the north bank, gradua decreasing the height of the dam upstream. This would throw much of the water as might be desired to the south side of the isla and away from the railroad, and then by building a dam across t south channel near the lower end of the island the flow of the strea could be controlled. Space for a power house on the island could cleared by a small amount of blasting, and the power be transmitt to Hot Springs, where there is a large area of level land. This is far the largest and most noticeable fall on the stream, and probab would afford a cheaper and easier development than any other.

As at this fall, so at all others between Paint Rock and Ash ville, the proximity of the railroad to the stream renders it impossib to build high dams, though otherwise the conditions for easy a cheap construction are very favorable, for everywhere stone can b obtained in great quantities at comparatively small cost for blastin and transportation to the site of the work.

Although the average fall per mile in the stream channel betwe the head of the Mountain Island Shoal and the mouth of Brush Creek is very great, there are several places where it is still more concentrated, the first of these being just above the mouth of Laurel Creek, where the fall is estimated to be about 15 feet in a little more than one-fourth of a mile, and about 2 miles below Barnard Station, where there is another large fall within a short distance. Just below and a little above the mouth of Brush Creek there is still another large fall, the banks being very high, steep, and rocky, the stream comparatively narrow, and all of the conditions for the construction of a high dam very favorable, excepting the presence of the railroad. At almost any desired place within this distance—from the Mountain Island Shoal to Brush Creek—falls of from 15 to 20 feet can be obtained.

From the mouth of Brush Creek to Asheville, a distance of 29.3 miles, the stream is still very rapid, but the average fall per mile is much less than in the section just described, being about 15.4 feet, in general well distributed. Sites where falls of 10 feet or more can b obtained are numerous, though none of them were noted particularly.

The first power developed on this stream is at Marshall, Madison County, where, on the south bank of the river, the Marshall Milling Company has erected a flour mill with a capacity of 75 barrels per day, utilizing only a small part of the flow, which is turned aside by means of a wing dam about 200 yards long extending diagonally upstream about half the width of the river, from the upper end of which a very low dam has been built to the north bank of the stream, both dams being made of logs and giving a fall of 13 feet at the wheel.

There are several other localities between Marshall and Asheville where small powers could be developed in the same way, but no attempts have been made to do this. There is a project to develop a small fall in the stream just below Asheville, to obtain power to operate street cars and electric lights, and a low dam has been built, but no other work has been done.

Above Asheville the character of the stream again changes and it becomes a placid river with a current which though rapid when compared with the streams of the Coastal Plain is very sluggish when compared with its mountain neighbors or with its own current a few miles below. The bed of the stream is overlain with a stratum of coarse sand and gravel, and in general is rather smooth, though the current is interrupted at intervals by ledges and bowlders, and the fall is very much more gradual and evenly distributed than is usual with mountain streams. The distance from Asheville to Brevard, by river, is 48.35 miles, and the total fall is 130.9 feet, making the average fall per mile only 2.7 feet. Indeed, so small is the fall that at one time the United States engineers did a great deal of work on this portion of the stream to render it navigable. Formerly a small steamboat plied the river, but it did not pay expenses, and of late no attempt has been made to navigate the stream.

There are two principal obstructions to navigation, the first of these 8½ miles above Asheville, and known as the Sandy Bottom Shoal. This is the largest shoal on this part of the river, the total fall being 22.6 feet in a distance of 18,000 feet. Three and one-half miles above this is the Long Shoal, where the fall is 18.3 feet in 12,920 feet. Above this and as far as Eastatoe Ford, about 1 mile above Jeptha, the stream flows placidly along through a broad and level valley and offers no possibility of power development. Above the ford, however, the fall rapidly increases, but the stream divides into the North and West forks, both of which are too small for consideration as power streams.

TRIBUTARIES OF FRENCH BROAD RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the drainage basins of the important tributaries in North Carolina were visited and the following measurements made:

Discharge measurements of tributaries of French Broad River in North Carolina.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 14	North Fork of French Broad River.	Two hundred yards above mouth of West Fork.	N. C. Curtis	....	100.6
Oct. 15	.....do	.....do	.....do	13.2	51.8
Sept. 16	.....do	Bridge on Brevard-Webster road.	.....do	14.98	107.48
Do	.....do	Ford on road between Tucker and Shoal creeks.	.....do	7.3	75.0

Discharge measurements of tributaries of French Broad River in North Carolina—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Dis-charge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 14	West Fork of French Broad River.	Near mouth	N. C. Curtis	2.20	149.0
Oct. 15	do	do	do		62.0
Sept. 14	Middle Fork of French Broad River.	Bridge 20 yards above ford	do	5.35	77.0
Do	South Fork of French Broad River.	Footbridge at ford of main road.	do	10.3	71.0
Oct. 15	East Fork of French Broad River.	Near mouth	do	10.2	46.0
Sept. 16	Tucker Creek	Two hundred yards above mouth.	do	4.61	28.0
Sept. 13	Cathey Creek	Ford of Brevard-Jeptha road	do	6.7	30.2
Sept. 17	King Creek	Brevard road	do	4.71	15.46
Do	Davidson River	Near mouth	do	16.45	151.77
Oct. 16	do	do	do	16.75	70.20
Sept. 17	Little River	Three-fourths mile above mouth.	do	13.66	182.8
Oct. 16	do	do	do	14.35	69.2
Sept. 17	Boylston Creek	Near mouth	do	5.85	28.65
Do	Mills River	Bridge on Old Haywood road	do	13.11	211.64
Oct. 17	do	do	do	13.4	94.0
Sept. 18	Mud Creek	Near mouth	do	5.11	108.0
Do	Caney Creek	Bridge on Westfall's place	do	10.1	60.0
Do	Avery Creek	Bridge on road from Mills River to Asheville.	do	6.56	11.31
Sept. 19	Hominy Creek	Asheville	do	15.1	80.0
Oct 17	do	do	do	15.4	24.0
Sept. 19	Swannanoa River	Biltmore	do	2.91	76.33
Sept. 20	North Fork of Swannanoa River.	Three miles above Swannanoa.	do	16.07	21.45
Do	Flat Creek	Two miles below Black Mountain Station.	do	4.05	22.83
Sept. 12	Beaverdam Creek	Fifty yards above mouth	E. W. Myers	5.09	1.46
Oct. 30	do	do	L. V. Branch	5.08	4.10
Sept. 16	Lees Creek	Olivette	E. W. Myers	11.15	3.95
Oct. 30	do	do	L. V. Branch	10.95	2.29
Sept. 12	Newfound Creek	At mouth	E. W. Myers	17.75	9.41
Sept. 16	do	Three-fourths mile above mouth.	do	10.19	34.16
Oct. 30	do	do	L. V. Branch	10.44	20.23
Sept. 12	Reems Creek	At mouth	E. W. Myers	12.1	4.89
Oct. 30	do	do	L. V. Branch		9.0
Sept. 11	Flat Creek	do	E. W. Myers	18.05	5.33
Oct. 29	do	do	L. V. Branch	17.43	5.0
Sept. 12	Sandymush Creek	Bailey	E. W. Myers	9.73	21.72
Sept. 17	do	do	do	9.43	55.23
Oct. 30	do	do	L. V. Branch	9.53	45.0
Sept. 16	Turkey Creek	Blackwell Springs	E. W. Myers	7.97	35.24
Oct. 30	do	do	L. V. Branch	8.32	16.24
Sept. 17	Big Ivy River	One-eighth mile below mouth of Bull Creek.	E. W. Myers	2.55	47.59
Oct. 29	do	do	L. V. Branch	2.72	41.72
Sept. 8	Little Pine Creek	One hundred yards above mouth.	do	5.84	3.33
Oct. 31	do	do	do	5.76	6.0
Sept. 8	Pawpaw Creek	One mile above mouth	do	4.6	0.36
Sept. 10	Walnut Creek	At mouth	do	23.24	1.36
Oct. 31	do	do	do	2.35	2.24
Sept. 8	Big Pine Creek	One hundred yards above mouth.	do	6.07	4.85
Oct. 31	do	do	do	6.01	4.45
Sept. 8	Big Laurel Creek	Two hundred yards above mouth.	do	16.13	49.0
Sept. 18	do	do	E. W. Myers	15.77	55.0
Sept. 7	Spring Creek	Near Hot Springs	L. V. Branch	2.00	15.0
Nov. 1	do	do	do	2.07	16.0
Sept. 7	Shutin Creek	do	do	2.61	0.45

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

The principal drainage basins are briefly described on the following pages, in order upstream.

LONG CREEK.

The first tributary of any size entering the French Broad above Newport, Tenn., is Long Creek, which flows in from the north, draining a small area. At the mouth the valley of the stream is very narrow, the mountains rising high and steep on either side, in walls of almost bare rock; but farther up the valley widens greatly, and it is estimated that above the forks about half of the basin is cleared land, being made up for the most part of rather low hills, with gentle side slopes timbered in pine and oak. Corn and wheat are the principal crops; about one-third of the cleared land is in grass.

At the time the stream was visited it was extremely low, its flow being too small to gage, but it was carrying a quantity of water estimated to be between one-fourth and one-third of a second-foot. The stream is said to rise very rapidly after rains, reaching an extreme height of about 4 feet above low water. The floods are of short duration.

BIG CREEK.

Big Creek, the next tributary, enters the river from the south, near Del Rio, draining an extensive area in the high and rugged Stone and Smoky mountains, almost the entire basin being forest covered and very steep and rough, with a great deal of rock exposed on the hillsides. The cleared land is confined entirely to the narrow strips bordering the stream, but it is small in amount, being probably less than 5 per cent of the area of the basin, which may thus be considered entirely forested.

When this stream was visited it was very low, carrying an estimated discharge of possibly 2 second-feet. It rises rapidly after rains, in consequence of the great steepness of the hillside slopes over its basin, and attains a maximum height of from 5 to 6 feet above low water.

LAUREL BRANCH, MOONEYHAM BRANCH, AND ROCK CREEK.

These are very small streams which are practically dry during severe droughts.

WOLF CREEK.

Wolf Creek is the next tributary. It is a small stream entering from the south, draining a long and narrow area which with the exception of one or two small patches of an acre or two near its mouth may be considered entirely wooded. The basin is rough and mountainous, with very steep slopes. The forest growth consists for the most part of pine, with a dense undergrowth and with some oak and chestnut. Extensive lumbering operations have been carried on on the mountain slopes over the basin, and much of the available timber has been cut, but the ground is densely shaded by the undergrowth and the nontimber trees.

This stream was not gaged, the quantity of water which was flowing, estimated to be about 0.5 second-foot, being too small to admit of measurement. It was stated by residents that the stream was then at its lowest stage. The maximum flood rise is between 4 and 5 feet.

SHUTIN CREEK.

The basin of this stream is similar to that of Wolf Creek, except that very little timber has been cut.

SPRING CREEK.

Spring Creek, entering the river from the south, at Hot Springs, is the largest tributary yet described. It rises in the extreme southern corner of Madison County, near Sandymush Bald, on the northeastern slope of the Newfound Mountains, and flows in a general northerly direction for a distance of about 20 miles, draining an area of 66 square miles. Its basin is in the midst of the high mountains, is steep, rough, and rugged, and is almost entirely forest covered, the cleared land being confined to the narrow stream valleys which constitute a very small proportion of the whole area, probably less than 10 per cent. The stream attained its minimum stage during the autumn of 1900, when it was measured and found to be carrying 0.45 second-foot. It has a maximum rise of about 6 feet during floods, which are said to be violent, but of short duration.

BIG LAUREL CREEK.

This stream, the next tributary of the French Broad, rises in two forks, one in the Bald Mountains, in the extreme northeastern part of Madison County, and the other in the Unaka Mountains, in the extreme northern part of the county. It drains an area of 141 square miles. Its basin is very rough and rugged, with a large proportion of steep, forested slopes, ranging from 15 to 50 degrees and showing a great deal of exposed rock, which is of a slaty character. For a considerable distance above its mouth the stream is in a deep gorge and could not be followed, but it was ascertained that the country was extremely rugged and contained no cleared land. The hills there lack the symmetry of those seen farther upstream, having steeper slopes and being broken into irregular shapes by the small valleys and gullies which extend up their sides.

The proportion of cleared land in the basin is small, not more than 25 per cent of the area being under cultivation. The cultivated areas are for the most part confined to the stream valleys and the lower uplands. Within the last ten years much land has been partially cleared by cutting away the undergrowth and deadening the larger trees, the deadened areas being largely cultivated in tobacco or corn. The soil is in part red, clayey, and very impervious to water, and in part loamy, and is not very fertile.

Extensive lumbering operations are now in progress over the basin, many small portable mills being located in close proximity to the timber, the lumber being hauled to the railroad at either Putnam or Stackhouse. Poplar seems to be the timber most sought, though oak and pine are also cut. Much chestnut remains, and trees of many other varieties are found.

At its mouth the flood rise of the creek is from 7 to 8 feet. It never falls very low, the lowest stage known having been reached in the autumn of 1900, when the discharge was about 49 second-feet. While the stream is capable of furnishing power in large amounts, it is utilized by only two or three small gristmills, grinding grain for local uses.

Some baryta has been found in the basin, but so far as could be learned the principal deposits of this mineral are along the main river, on the hills between Stackhouse and Marshall. Talc is also found in this region, and some has been recently taken out which is said to be of excellent quality.

Shelton Laurel Creek.—This stream is the principal tributary of Big Laurel Creek. Its drainage basin is very similar to that of the main stream, although as the creek is ascended the topography flattens out to some extent. The stretch of the river between White Rock and Alleghany is much more level and more extensively cultivated than any seen lower down the stream. The only extensive lumbering operations carried on in the basin are in this locality, being mainly directed against the timber which can be reached from the small tributary streams, although the operations are more or less general.

The soil seems similar to that along Big Laurel Creek, but it contains a very large proportion of rock fragments ranging in size from a pea to several inches in diameter, and more quartz is seen, forming now an important part of the country rock.

The slope of the channels of this creek and its branches is very great, the storm waters reaching the streams almost immediately, the main creek rising very rapidly and falling as quickly.

BIG PINE CREEK.

The next tributary gaged was Big Pine Creek, which enters the French Broad from the south, opposite Barnard, draining a considerable area which is largely forest covered, the cleared and cultivated land being confined for the most part to the stream valley and the lower hills. The hillside slopes over the basin are almost uniformly steep and rocky, and the greater part of the area is mountainous.

WALNUT, LITTLE PINE, AND HAYES CREEKS.

Walnut Creek, entering from the north, about 3 miles above Barnard, is a stream of about the same size and general character as Big Pine Creek, except that the proportion of cleared and cultivated land in its drainage basin is considerably greater, the valley of the stream being wider and the slopes less steep and rugged, the topography consisting for the most part of rather low and rounded hills, largely grass covered, although the upper part of the basin is steep and mountainous. The cleared land amounts to probably one-third of the whole area, possibly more. The stream reached a very low stage in the autumn of 1900, lower than ever before known, it is stated. The discharge measured on September 10 was 1.36 second-feet. The maximum rise in flood is about 4 feet.

Little Pine Creek and Hayes Run are entirely similar streams, though much smaller.

IVY RIVER.

Ivy River, the next tributary, enters the French Broad from the east, and is the principal tributary in North Carolina. It rises on the western slopes of the Great Craggy Mountains, near Yeates Knob, the headwaters being at an elevation of about 5,000 feet, and flows in a general westerly direction, joining the French Broad about 2½ miles above Marshall, draining an area of 176 square miles.

For about 3 miles above its mouth the valley of the river is very narrow and the banks of the stream are steep, showing much exposed rock, but they are forested with a growth of considerable density. Above this 3-mile stretch, although the gorge formation still persists for a considerable distance, the hills do not rise to so great heights, and the country beyond the summit of the bluffs is composed of a succession of hills and ridges of moderate height, very sharp topped, and inclosing narrow V-shaped valleys, the hillside slopes ranging from 10 to 30 degrees. A large part of the area—perhaps 75 per cent—is cleared. It is probable that nearly 50 per cent of the whole area drained by Ivy River is either under cultivation or is grass. Throughout this part of its course, or to beyond Grantville, the stream channel is very tortuous.

As the stream is ascended the topography becomes less strongly marked and the country better fitted for agriculture and stock raising, until a short distance below Barnardsville the mountains begin again to encroach on the river and the cultivated lands are confined to the immediate valley of the stream. There is considerable timber yet standing in the high mountains about the headwaters, much of it being inaccessible.

Corundum has been found near Democrat, nickel stainings have been observed in the rocks at many localities, and a vein of serpentine of good quality crosses part of the basin.

The stream has a large fall throughout its length, the average fall per mile between its mouth and Barnardsville, at the junction of the forks, being about 43 feet. It could be made to furnish power in large amounts, but as yet very little has been done in that direction. About 1 mile above its mouth there is a fall of 6 feet in 200 feet, over ledges of solid rock, the width of the stream being between 60 and 70 feet.

The most important power site on the stream is about 2 miles above its mouth. Here Mr. W. B. Ellis, of Asheville, and others, have planned a large power development, which is about half completed. The plans include an arched masonry dam 95 feet in height, 360 feet long on top, 60 feet wide at base, and 12 feet thick to the 83-foot level. The race is to be 860 feet long from the dam to the power house, built partly in embankment and partly in open rock cut, with 100 feet of tunnel and 250 feet of steel flume, which will carry the water to a pair of 22-inch turbines. It is stated that the flow of the stream will be sufficient, with proper storage, to develop 2,000 horsepower under a working head of 110 feet, the natural flow of the stream yielding 1,000 horsepower under that head. The power is to be transmitted electrically to Asheville, Marshall, and other places at a potential of 10,000 or 11,000 volts. During the autumn of 1900, when the plant was last visited, all work had been suspended, due largely, it was rumored, to lack of water.

On the basis of 1,000 horsepower developed continuously, the flow of the stream at this place is calculated as follows: It is safe to assume that the losses of energy in the wheels, dynamos, and in transmission will amount to at least 20 per cent of the total energy due to the water, and as it is the intention to deliver 1,000 horsepower at the end of the transmission line, this will require of the stream a flow capable of developing 1,250 gross horsepower with a head of 110 feet, or 11.36 gross horsepower per foot of fall. One second-foot of water falling 1 foot will yield 0.1135 gross horsepower, so that in order to produce 11.36 gross horsepower per foot fall a flow of practically 100 cubic feet per second will be necessary, and during times of drought the stream does not carry that amount of water. When these notes were made, in October, 1899, although the discharge could not be gaged, it was estimated to be not much more than 50 second-feet. When the locality was visited in the fall of 1900, at a time when the stream was said to be very low, the discharge was gaged a short distance above the head of the backwater from the dam and a flow of 41.72 second-feet was found.

Just above the mouth of Little Ivy River there is a gristmill with an 8-foot dam, giving a fall of 10 feet, and at Democrat there is a similar mill.

SANDYMUSH CREEK.

The next tributary is Sandymush Creek, which joins the French Broad about 4 miles above the mouth of Ivy River. This creek rises on the northern slopes of the Newfound Mountains, in a number of small creeks which have a general northerly or northeasterly course. Including Turkey Creek, which joins it near its mouth, it has a drainage area of 86 square miles. Near its mouth and for a considerable distance upstream the creek lies in a deep and narrow gorge, but farther up the valley widens very much and the topography becomes less strongly marked over a large part of the area. The high hills which inclose the valley are rough and steep, most of them ranging from 15 to 30 degrees, but many of them being much steeper. The proportion of cleared land is smaller than in the basin of Turkey Creek, being less than half of the whole area. Above the junction of Little Sandymush Creek the area is entirely mountainous and forested, with the exception of small, narrow areas immediately along the stream. Pine trees seem more numerous than heretofore noted, the character of the hard-wood growth remaining the same, also the agricultural products. The soil is a fertile loam, the country rock a much laminated and contorted gneiss.

The stream is said to have reached its minimum stage of flow during the fall of 1900 (see measurements in table on page 128). During floods it is subject to violent rises of from 6 to 7 feet.

Turkey Creek.—The valley of this tributary of Sandymush Creek is very different in character from that of the main stream. In proportion to its size its valley is broader than that of any stream yet described. The proportion of cleared land seems to be about 75 per cent over the lower part of the basin, and is probably 66 per cent of the whole area. The topography is a succession of hills and ridges divided by broad valleys, and the hillside slopes are comparatively gentle. The soil is deep and fertile. The country rock seems without exception a gneiss. At the time the stream was visited all of the land except that in corn was covered with grass, and this is true of all this section of country during the fall and summer months. A large part of the area is planted in wheat, and when that is harvested grass quickly covers the land, remaining until seeding time comes again.

The creek falls very low at times, reaching, it is said, its lowest stage in the fall of 1900, and though subject to floods of 6½ to 7 feet, these are rare and generally of short duration.

FLAT CREEK.

The next tributary is Flat Creek, which enters the French Broad from the east, about 1 mile below Alexander. It is a small stream rising on the western slope of the Flat Creek Mountains and draining a broad and flat valley of considerable extent. The topography is in broad and low flattened hills and ridges, the hillside slopes being very gentle. Seemingly about two-thirds of the area is cleared land, about one-half of it in grass and the other half chiefly in wheat, corn, and tobacco. The soil appears deep and fertile. No exposed rocks were seen, though the basin is underlain by gneiss or granite. The stream is subject to periods of very low flow, and during floods it rises from 5 to 6 feet at the mouth.

REEMS, NEWFOUND, AND BEAVERDAM CREEKS.

Reems Creek, the next tributary, enters the river from the east a short distance above Alexander, and seems in every respect similar to Flat Creek, just described. It was gaged at its mouth, with the results given in the table on page 128. The maximum flood rise is from 5 to 6 feet.

Newfound Creek, entering the French Broad from the southwest, rises close to the headwaters of Turkey Creek, near Turkey Creek Pinnacle, and in soil, topography, and general characteristics is a stream similar to Turkey Creek.

Beaverdam Creek, entering the French Broad from the east a short distance below Owenby, drains a long, narrow, and rather flat valley containing a large proportion of cleared land, but it is a small and unimportant stream.

SALUDA RIVER.

About 10 miles above Greenville, S. C., Saluda River is formed by the confluence of the North Saluda and the Middle Saluda. The South Saluda, a stream nearly or quite as large as the two other streams combined, enters the Middle Saluda a few miles above the junction of the latter stream with the North Saluda. The watershed of these three branches is defined by the North Carolina–South Carolina boundary line, extending from the Greenville-Pickens county line in South Carolina to the western slope of Rocky Spur, 5 miles southeast of Saluda, N. C., the total length being about 36 miles and the drainage area estimated at about 380 square miles. The watershed includes the southern slopes of the Saluda Mountains and a portion of the Blue Ridge. Below the junction of the three forks the main stream flows in a general southeasterly direction through the State of South Carolina, joining Broad River near Columbia, to form the Congaree.

The steep slopes at the headwaters of the river are densely forested, but the valleys of even the smaller tributary streams have been cleared. Oak and hemlock predominate, but pine and other timber are frequently intermingled. The trees are not in good condition, however, owing to frequent scars from fire and other destructive agencies. The soil is largely composed of material derived from the decomposition of granite and gneiss. In many parts of the basin it has a thick layer of humus and is very fertile; in other parts, however, a clay is formed which is impervious to water and not well suited to agriculture. The soil in the former places will not withstand the action of flowing water, and where the forests have been cut considerable washing of the top soil can be observed. In the lower part of the drainage basin the soil is sandy and is largely devoted to agriculture, the chief crops being cotton, sugar cane, and sweet potatoes.

The Saluda is largely outside of the mountain region, its headwaters only being on the slopes of the Blue Ridge. For this reason it is perhaps not of as great importance in the investigation of the proposed Southern Appalachian Park as the streams which rise and flow for many miles through the mountains. The preservation of the forests, however, is of the greatest importance, owing to the nonresistant character of the soil and the danger of heavy wash and floods.

NORTH SALUDA RIVER.

This stream rises on the western slope of Rocky Spur and Hogback Mountain, at an elevation of 2,600 feet. It is 25 miles long and flows in a general southwesterly direction, joining the Middle Saluda about 3 miles below the confluence of that stream with the South Saluda. The elevation at the junction is about 980 feet. The average fall per mile is therefore about 65 feet. Most of this fall, however, is on the upper portion of the stream, the average fall per mile for a distance of 20 miles above the mouth of the North Saluda being only about 25 feet.

Around the headwaters of the stream about 15 per cent of the watershed has been cleared. The western sides of Rocky Spur, Hogback Mountain, and Glassy Mountain and the eastern slopes of the Saluda Mountains have been very little cleared, while the southern slopes of the latter mountains are especially well wooded. No lumbering is being done in this section, and the land cleared for farming purposes is proportionately small. As a natural consequence of its forested basin the waters of the stream are never very muddy, although they are said to contain more sediment than either the Middle Saluda or the South Saluda.

After leaving the mountains the flood plain of the river broadens, and the wide, flat bottoms are given up largely to agriculture, the chief crop being corn, although considerable cotton is raised. Discharge measurements were taken on the North Saluda 2 miles below Humphries's store, at Lima, and at Marietta, with the results given in the table on page 138. The river has an average annual fluctuation of 10 feet.

Fall Creek, a small tributary flowing into the North Saluda about midway between Humphries's store and Lima, has a fall of about 120 feet to the mile and a mean discharge of 6 or 8 second-feet.

MIDDLE SALUDA RIVER.

The Middle Saluda rises in Jones Gap, in the Blue Ridge, on the North Carolina-South Carolina boundary line, at an elevation of 3,000 feet. Its total length is about 20 miles; the elevation at its mouth 990 feet. It has an average fall of 100 feet to the mile, but, as in the case of the North Saluda, the fall is much greater in its upper portion than in its lower course, the average fall for 10 miles above its mouth being only 11.6 feet per mile.

The drainage conditions affecting the flow of the stream are similar to those of the North Saluda. Its flood plain is quite broad below Riverview and is under cultivation. The soil in the river bottoms is rich and loamy and black in color, while the hills are covered with a deep, rather rich, light-red soil. A large amount of cotton is raised around Marietta, and below that place cotton constitutes the chief crop.

The water power is better than that of the North Saluda. The Cleveland mill, on Mill Creek, a tributary from the east, is a small sawmill and gristmill having a working head of about 12 feet. Below it shoals are quite frequent on the main stream. Opposite Marietta there is a shoal a half mile long, called Long Shoal. The fall is possibly 10 feet in 200 feet. Two miles below the Long Shoal there is a sawmill and gristmill having a dam about 6 feet high and a working head of 12 or 15 feet. The average annual fluctuation of the Middle Saluda is 9 feet.

SOUTH SALUDA RIVER.

This branch has a total length of 30 miles. It rises just behind Pinnacle Mountain, at an elevation of 2,700 feet. The difference in elevation between its head and mouth is 1,720 feet, the average fall per mile 57 feet. It has one large tributary, viz, Oolenoy (sometimes called Illinois) Creek, a stream about 10 miles long, with an average fall of 30 feet to the mile below Sunnydale. It has wide and fertile bottom lands, planted chiefly in corn. The upper watersheds of both South Saluda River and Oolenoy Creek have been practically untouched by the woodman's ax.

The only fall observed on the South Saluda was 8 miles west of the Cleveland mill, just below the bend in the stream. The fall there is 30 feet in 100 feet, but the building space is rather cramped. The flood plain of the river varies in width from 50 to 200 yards, and the soil is deep and rich.

The scenic features of the region surrounding the headwaters of the South Saluda and the Middle Saluda are remarkably striking.

The southern slopes of the Blue Ridge are very steep. Table Rock, a mountain with an elevation of 3,157 feet, is surrounded by an escarpment of bare rock on all sides except one, and presents a very forbidding appearance. There is a popular summer resort, owned by Furman University, on Cæsars Head Mountain.

DISCHARGE MEASUREMENTS.

During the investigation measurements were made of the North Saluda, the South Saluda, the Middle Saluda, and Fall Creek, as shown in the following table. A gaging station has been maintained on the main river at Waterloo, S. C., since August 30, 1896, the results obtained being published in the subsequent annual reports of the Survey.

Discharge measurements of Saluda River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
May 24	Saluda River	Greenville, S. C	N. C. Curtis	34.5	1,594.0
1900.					
Sept. 7	South Saluda River.	Freeman Bridge, below mouth of Middle Saluda River.	do	14.1	223.0
Oct. 14	do	do	do	14.1	171.0
1901.					
May 3	do	do	E. W. Myers	12.4	469.0
1900.					
Sept. 7	do	2 miles above mouth of Middle Saluda River.	N. C. Curtis	6.0	188.0
Oct. 14	do	do	do	6.0	134.0
1901.					
May 3	do	do	E. W. Myers		290.0
1900.					
Sept. 7	Middle Saluda River.	1 mile above mouth	N. C. Curtis	11.75	68.0
Oct. 13	do	do	do		55.0
1901.					
May 2	do	do	E. W. Myers	10.3	181.0
1900.					
Sept. 7	North Saluda River.	Iron bridge at Marietta	N. C. Curtis	14.7	58.2
Oct. 13	do	do	do	14.17	80.0
1901.					
May 3	do	do	E. W. Myers	13.5	168.0
1900.					
Sept. 6	do	Bridge on Lima-Cleveland Mill road.	N. C. Curtis	12.9	56.1
Do	do	2 miles below Humphries's store.	do	14.2	28.1
Do	Fall Creek	Bridge on road to Lima	do		[a]15.0

[a] Estimated.

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

BROAD RIVER.

PHYSICAL FEATURES.

Broad River rises on the eastern slope of the Blue Ridge, in McDowell County, N. C., between the Swannanoa and the Edmondson mountains. It flows in a southwesterly direction through Hickory Nut Gap (see Pl. XXXIII), until it is joined by Green River, when it bends to the east and maintains that course for about 20 miles. After it is joined by the First Broad it turns abruptly to the south and crosses the North Carolina boundary line near Shelby. The river and its tributaries were examined as far down as Dellinger, S. C., about 1 mile from the State boundary line. Its drainage area in North Carolina includes portions of Henderson, Polk, Rutherford, McDowell, and Cleveland counties, and aggregates 1,400 square miles. Its total drainage area is 4,950 square miles.

Three important branch streams contribute their waters to those of Broad River, two entering from the north, called First Broad and Second Broad, and the other entering from the west and known as Green River. These streams drain an area of the Blue Ridge and adjacent ridges extending to the State boundary line in Henderson County to and including the south side of the South Mountains in Rutherford and Cleveland counties. Pool Creek, a small branch from the south, discharging 6 or 8 cubic feet per second, is interesting on account of the pools which have been formed through the action of the water. There are three of these pools, each resembling a huge auger hole 6 feet in diameter. No definite information was obtainable as to their depths. Buffalo Creek, a small stream rising on the east side of the Bald Mountains and entering Broad River from the north, has a wide flood plain near its mouth and an average rise of 6 feet. Just above Ayr it is said to have a fall of 30 feet. This stream was not visited.

After leaving Batcave, where it is joined by Hickory Nut Creek (a typical headwater tributary shown in Pl. XXXIV), Broad River flows for 6 miles through a gorge which is justly famous for the grandeur of its scenery and the number of interesting natural curiosities. The mountains rise abruptly on either side to a height of 200 feet above the stream bed, and for about three-fourths of the way up are clothed with a thick forest growth. The upper side of each slope is guarded by an escarpment of granite absolutely bare of all verdure. This wall of rock varies in height from 200 to 1,000 feet. On the northeast corner of Sugarloaf Mountain and overlooking the gorge is a perpendicular mass of rock called Chimney Rock, which is detached from the face of the mountain and stands a massive silhouette against the sky. Its greatest height is 213 feet, its diameter at the summit 60 feet. The top of the rock is reached by a wooden stairway. A half mile directly west of Chimney Rock are the falls of Fall Creek, which are said to have a sheer drop of several hundred feet, but the quantity of water is insufficient for water power. On the left bank of the river is a mountain known as Old Rumbling Bald.

The region possesses a great variety of scenic and agricultural features. The soil is generally loose and porous. The headwaters of Broad and Green rivers rise among the high peaks of the Blue Ridge, and after winding their way through gaps and gorges finally emerge and flow through a region of low, rolling hills. There is very little bottom land along any of the larger tributaries. The only extensive stretches observed were along the lower portions of Whiteoak Creek and Cove Creek. The entire region is very healthy. The country east of the Blue Ridge, including the watershed and the drainage basin of Broad and Green rivers, is fair for farming purposes, though the soil is not especially rich. The chief crops in this section appear to be corn and wheat.

RAINFALL.

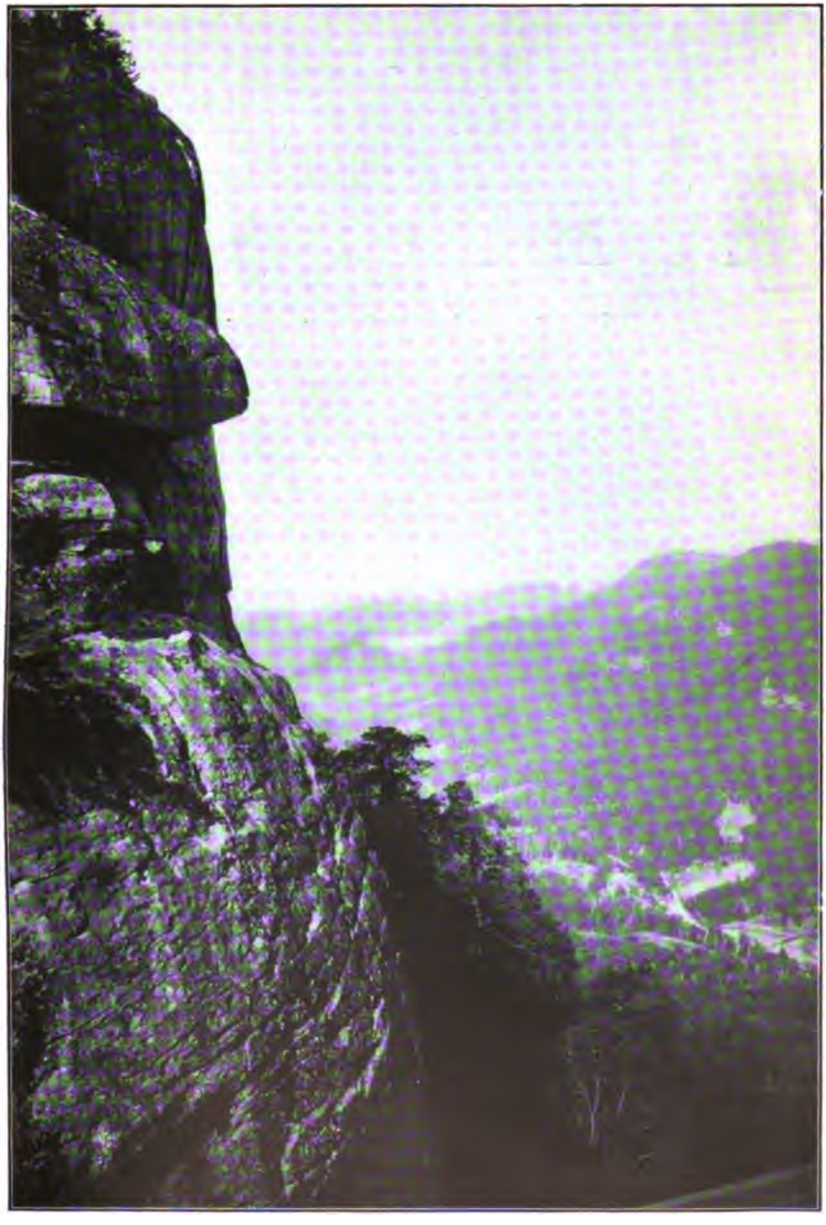
The rainfall in the basin of Broad River is approximately 51 inches, distributed throughout the year as follows: Spring, 13 inches; summer, 13 inches; autumn, 10 inches; and winter, 15 inches. The rainfall in the region above the headwaters is, however, probably much greater than this. The bed of the stream is of rock, clay, sand, or gravel, but in many places the banks are low and the bottoms are overflowed during freshets.

FORESTS.

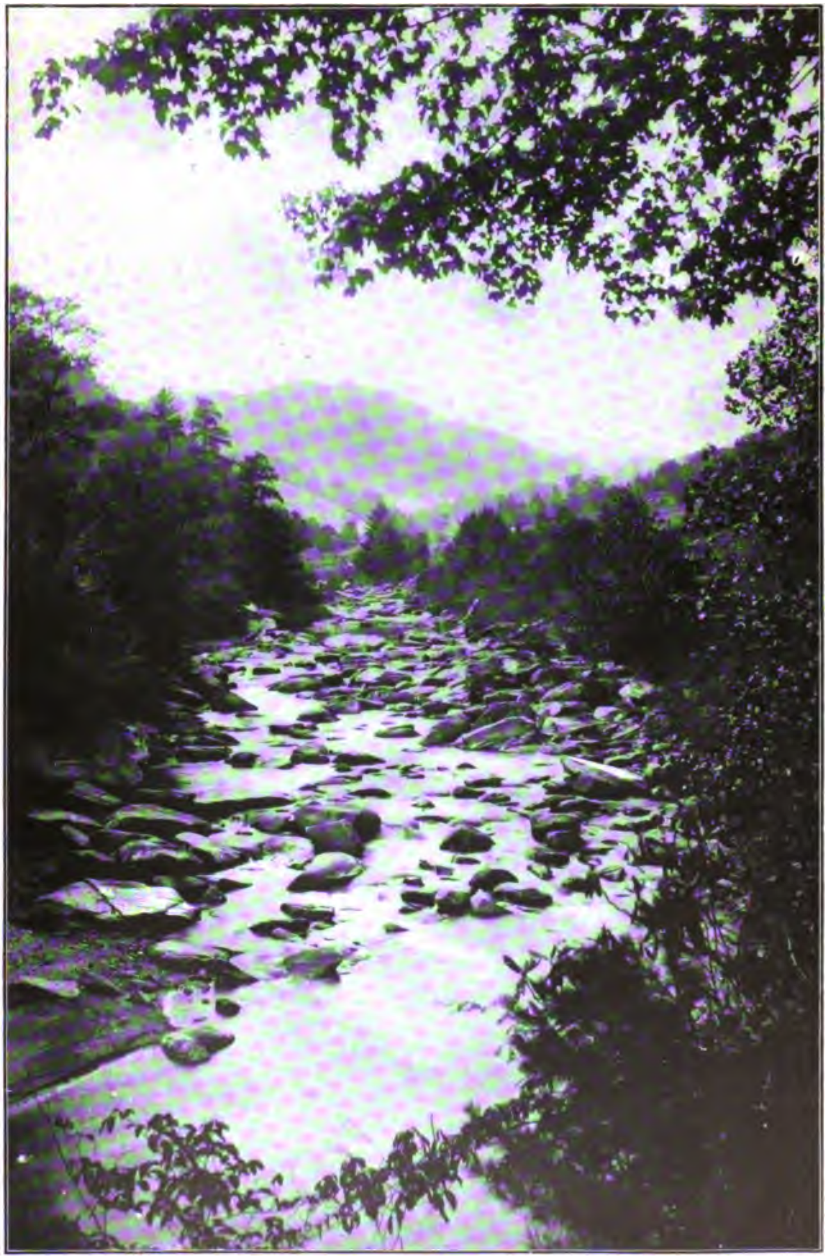
The timbered areas are comparatively small. Very little clearing has been done around the headwaters of either Broad River or Green River. The drainage basins of the Broad proper, the First Broad, and the Second Broad contain little valuable timber. For 2 miles above Batcave the land has been considerably cleared for farming, corn being the chief crop. The upper watershed of Reedy Patch Creek has been entirely cleared, and extensive clearing has been done around the heads of Cove, Maple, and Mountain creeks.

MINERALS.

The mineral wealth of the Broad River region is considerable. Deposits of gold are found about the headwaters of the First Broad, the Second Broad, and Silver and Muddy creeks, and these have been worked in a crude way since 1830. Several mines are also being worked on the flanks of the South Mountains, the ore being a



HICKORY NUT GAP FROM CHIMNEY ROCK, NORTH CAROLINA.



HICKORY NUT CREEK, NORTH CAROLINA.

very good grade of sulphuret. Here the famous Bechtler dollar was formerly coined. Monazite is extensively mined and shipped to the North and to foreign countries. Copper, corundum, and tin are among the minerals obtained.

DISCHARGE MEASUREMENTS.

During the investigation two gaging stations were established on Broad River, one at Dellinger, S. C., and the other near Alston, S. C., and measurements were made at these stations and at other places on the main river, as shown in the following table. Measurements of the tributary streams are given in the table on page 143.

Discharge measurements of Broad River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
Feb. 28	Near Alston, S. C	E. W. Myers	5.40	8,913.0
Apr. 18	do	do	6.28	
Apr. 20	do	do	13.60	44,456.0
May 22	do	do	3.40	4,406.0
July 5	do	do	4.25	5,962.0
Aug. 17	do	do	2.80	2,840.0
1901.				
May 7	Near Blacksburg, S. C	do	2.50	2,418.0
1900.				
Aug. 30	At Dellinger, S. C	do	0.80	1,430.0
Aug. 28	Ford 1 mile above mouth of Second Broad River, North Carolina.	H. A. Pressey	5.95	649.0
Aug. 25	McClure's bridge, North Carolina	N. C. Curtis	23.43	220.0
Oct. 18	do	do	22.67	434.0
1901.				
Aug. 9	do	do	20.8	683.5
1900.				
Aug. 22	Near mouth of Buffalo Creek, North Carolina.	do	15.2	57.1
Oct. 6	do	do	14.59	145.4
1901.				
Aug. 10	Near Chimney Rock, N. C	do	14.1	247.6
1900.				
Aug. 21	Bridge at Batcave, N. C	do		50.1
Do	do	do	10.15	48.0
Oct. 6	do	do	10.45	62.4

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of all the measurements in the above table except those made near Alston and at Dellinger, where bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter case, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The average annual fluctuation of the river at its mouth and near Buffalo Creek is 10 feet; at Batcave it is 8 feet.

WATER POWERS.

Broad River rises at an elevation of 3,100 feet. The elevation at the junction of Broad and Green rivers is about 780 feet. The total length of this portion of the stream is about 40 miles and the difference in elevation 2,320 feet, making the average fall per mile 58 feet. The average fall per mile from its head to its junction with Hickory Nut Creek, at Batcave, is 125 feet. From Batcave to a half mile below the mouth of Pool Creek the fall is also 125 feet per mile, but from that point to the mouth of Green River the fall is only 8 feet to the mile. As far down as Batcave the stream has a flood plain of about 75 yards average width, with no very steep slopes on either side. Hickory Nut Creek, a small stream entering the river just above the mouth of Reedy Patch Creek, has an average fall of 175 feet per mile, and the latter stream a fall of 150 feet per mile.

The water power of the upper section of the river is excellent and has been very little developed. Rock ledges are numerous, and falls of 8 feet in 100 feet frequently occur. The only obstacle is the absence of good building sites. There are three mills between Batcave and Pool Creek, each having a working head of about 10 feet.

The distance between Poors Ford and Dellinger is 25 miles. The water powers, descending the stream, are, briefly, as follows: (1) Big Island Ford Shoals, 1½ miles below Poors Ford, having a vertical fall of 3 feet and a slope of probably 6 or 7 feet in 400 yards, with good rock bottom and natural abutments; (2) Durham Shoals, 6 miles below the mouth of Second Broad River, with a vertical fall of 7 feet, which could be increased to 12 feet at the wheel, and with excellent foundations for a dam and building; (3) Palmers Shoals, 1 mile below the mouth of First Broad River, with a fall of about 18 feet in a half mile (the south bank at these shoals is nearly level, but the rock cliff juts out prominently on the north bank); and (4) Hopper and Blanton shoals, where the river makes a horseshoe bend and the difference in elevation across the neck is said to be 30 feet, the short shoal on the lower side of the neck being known as the Hopper Shoal and the one on the upper side as the Blanton Shoal. The latter power could be developed by piercing the neck of the tunnel and damming the water at the Blanton Shoal.

TRIBUTARIES OF BROAD RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the principal tributaries of Broad River, in order upstream:

Discharge measurements of tributaries of Broad River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
May 24	Enoree River	Greenville, S. C	N. C. Curtis	7.7	160.0
Do	Tiger River	14 miles east of Greenville	do	19.5	174.0
May 25	Pacolet River	Clifton, S. C	do	13.1	900.0
1900.					
Aug. 30	First Broad River	Near mouth	do	17.7	285.3
Oct. 10	do	do	do	16.2	266.4
Aug. 23	Puzzle Creek	do	do	6.70	10.0
Aug. 24	Robersons Creek	At mouth	do		24.0
Aug. 23	Hollins Creek	do	do	5.8	14.3
Do	Cathey Creek	do	do	8.35	42.0
Aug. 24	Cane Creek	1 mile above mouth	do	5.43	17.0
Do	Second Broad River.	Bridge on Rutherfordton-Morganton road.	do	7.35	55.0
Oct. 4	do	do	do	7.00	64.0
1901.					
Aug. 13	do	Iron bridge near Bostic Station	do	23.45	273.3
1900.					
Aug. 23	do	1¼ miles east of Forest City	do	20.8	153.3
Oct. 5	do	do	do	20.32	188.3
Aug. 31	Whiteoak Creek	One-half mile above mouth	do	4.65	64.0
Sept. 3	Cove Creek	Near mouth	do	5.40	19.2
Do	Green River	Near Saluda, on Howard Gap road	do	17.7	74.1
Aug. 25	do	Cox's bridge	do	22.9	299.0
Oct. 8	do	do	do	22.6	255.4
1901.					
Aug. 9	do	do	do	21.0	833.2
Aug. 25	Maple Creek	Near mouth	do	7.70	8.4
Do	Mountain Creek	do	do	6.83	55.3
Oct. 8	do	do	do	6.48	70.2
Aug. 22	Cove Creek	Bridge at Rutherfordton road	do	18.65	69.3
Oct. 6	do	do	do	18.16	86.0
Aug. 22	Buffalo Creek	15 yards below main ford	do	4.10	17.0
Aug. 21	Reedy Patch Creek.	At mouth	do	5.75	13.0
Do	Hickory Nut Creek.	do	do	4.80	15.2

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Brief descriptions of the drainage basins and water powers of the three largest tributaries are given on the following pages.

FIRST BROAD RIVER.

This tributary rises on the southern slopes of the South Mountains, in the northern part of Cleveland and Rutherford counties, N. C., and flowing south joins Broad River about 8 miles south of Shelby, N. C. It drains an area of 302 square miles. The fall between the crossing of the railroad from Shelby to Rutherfordton and the mouth of the stream is about 105 feet, or at the rate of 8 feet per mile. The width of the stream at its mouth is about 90 feet.

The water powers on the First Broad are as follows: Ten miles north of Shelby and 3 miles north of the Double Shoals, where is located Cleveland cotton mill No. 2, which contains 4,224 spindles and is run by water power exclusively, a fall of 13 feet being utilized. At the Double Shoals there is a cotton factory which contains 2,000 spindles run by water power. The dam is 9 feet high, giving a total fall of 15 feet. Three miles southwest of Shelby are the Lauraglen cotton mills, containing 3,500 spindles operated entirely by water power. The dam is 14 feet high and 200 feet long, the fall of water at the mill 15 feet. Chambers's gristmill, still farther downstream, utilizes a fall of 9 feet, though more is available—the stream at this point will probably afford 7 or 8 horsepower per foot of fall in the low season of dry years. Stices's Shoal, about 4 miles from the mouth of the river, has a natural fall of 6 feet in a distance of 80 feet over a smooth rock bed, with considerable fall below. By the construction of a dam across the upper part of this shoal the fall could be increased still more. The Buck McSwain Shoal is about 1 mile above the mouth of the river, and has a natural fall of 3 feet in 150 yards.

SECOND BROAD RIVER.

This stream rises on the southern slopes of the South Mountains, in McDowell County, N. C., about 10 miles directly south of Marion. It flows in a southerly direction, meeting Broad River about 8 miles below the confluence of Broad and Green rivers. It drains an area of 193 square miles, and has a total length of about 50 miles. The elevation of its headwaters is 1,500 feet, of its mouth about 700 feet, giving an average fall per mile of 16 feet.

Comparatively little clearing has been done around the headwaters of either Second Broad River or Cove Creek, a tributary of Broad River which rises near the Second Broad and drains a considerable portion of the southern slopes of the South Mountains. The proportion of cleared land here is estimated to be about 10 per cent of the entire area. Lower down, however, along Cathey and Robersons creeks, the amount of cleared land is much greater, probably 50 or 60 per cent of the whole. After leaving the South Mountains the river flows through a region of low, rolling foothills. The timbered areas are thinly covered, the trees being chiefly pines and scrub oaks. The soil is rather compact, of a light-yellow color, and not particularly rich, and permits fairly good roads to be constructed without much difficulty.

Rutherfordton, the county seat of Rutherford County, about 6 miles west of the Second Broad, is on the western boundary of the cotton belt. The farming lands of Cleveland County and the eastern half of Rutherford County are mainly devoted to the production of cotton. Some sorghum cane also is raised, and the farmers usually make enough molasses for their own consumption. As the headwaters of the Second Broad and Cove Creek are approached the soil increases in fertility. The Cove Creek Bottoms are especially adapted to the production of corn, and along the slopes of the South Mountains tobacco is easily grown. The climate of the region is salubrious, and very little sickness prevails at any season of the year.

The waters of the First Broad and the Second Broad are never clear, even after protracted droughts, but are a sort of light-brown or yellow-ochre color. This is due to the character of the soil and to the extensive clearing which the watersheds have undergone. The beds of both streams are sandy except where rock shoals occur.

There are four cotton mills in operation in the Second Broad River region. The motive power of two of them is supplied by steam and of the other two by water. One of the steam mills is at Rutherfordton and the other at Forest City. The two water-power mills are known as Henrietta No. 1 and Henrietta No. 2. The former is 6 miles above the mouth of the river, at High Shoals, the latter about 7 miles above the mouth, at Caroleen. Both factories are connected with the Seaboard Air Line Railroad by branch lines. Henrietta mill No. 2 occupies the shoals formerly known as Harrells Shoals and Old Burnt Factory Shoals. A masonry dam about 24 feet in height gives a fall at the wheel of 29 feet. The natural fall of the shoals is 18 feet. The mill contains 35,000 spindles and 1,000 looms. At Henrietta mill No. 1 the natural fall is 23 feet, but a stone dam, slightly curving upstream, 17.8 feet high, gives a fall at the wheel of 32 feet. This dam is 200 feet long. The race is 300 feet long, 35 feet wide, and 10 feet deep. The mill operates 25,000 spindles and 1,000 looms. Both factories have auxiliary steam plants, and seem to have been extremely successful and profitable to their owners. The cotton used is raised in the immediate vicinity and hauled to the mills on wagons. About 2 miles from the mouth of the river the stream makes a long curve, the hillsides closing in very close to either bank. A site has been surveyed here for a large mill, and land has been cleared and construction begun. The natural fall between this site and Henrietta mill No. 1 is about 40 feet. A dam 23 feet high is to be built. No race is to be constructed, but the wheels are to be located at the dam. The fall below the shoals is abrupt for a short distance, and the waste water will flow off readily. The building site is fairly good. This dam will destroy the water power of Tumbling Shoals, 3 miles above the mouth of the river.

GREEN RIVER.

Green River rises in Henderson County, near the Transylvania County boundary line, on the northwestern slopes of the Saluda Mountains. The elevation of its headwaters is 2,900 feet, of its mouth 780 feet, the difference in elevation being 2,120 feet. The total length of the river is about 45 miles, making the average fall per mile about 47 feet. The distance from its head to the point where it emerges from the Blue Ridge is 23 miles, and the difference in elevation between the two points 1,800 feet, making the average fall per mile in that section 78 feet. The length of the remaining section is 22 miles and the difference in elevation 320 feet, making the average fall per mile only 15 feet. The drainage area is 198 square miles.

Along the upper portion of the river the mountain slopes shut in very close, and the timber on the watersheds is practically untouched. Consequently the flow of the stream is constant and the water always clear and cold. The scenery up Green River Cove and around Saluda while beautiful is not remarkably grand. The two most conspicuous mountain peaks are Whiteoak and Tryon. The latter has an elevation of about 3,200 feet.

Between Zirconia and the mouth of Cove Creek the river flows in a narrow gorge. The water power of this section is excellent, but building sites are scarce. The two water powers which are considered among the best on the stream were visited. The first of these, the Pot Shoals, is about 2 miles below the Southern Railway bridge. The fall consists of a drop of 8 feet and a total fall of possibly 30 feet in 100 feet. There is a fairly good site for a building here and excellent facilities for constructing a dam. The next power is at The Narrows, about 4 miles below the Pot Shoals. Here the stream is forced to pass through a narrow and rocky channel 7 feet wide and 50 feet long. The fall is about 10 feet in 100 feet. Building facilities are poor. Another power on the river, known as the falls of Green River, is not so well located as are the Pot Shoals. Here "the fall is about 30 feet in 100 feet, preceded by rapids for three-eighths of a mile, making a total fall of 45 feet. The banks are rocky and very steep, so that building facilities are not good." On the whole, the water powers of Green River are better than those of the Upper Broad, but they are not so accessible, and the building sites are poor. The average annual fluctuation of the river at its mouth is 11 feet; near Saluda it is 9 feet.

The healthfulness of the Green River region is unexcelled. Saluda and Tryon, situated on the Asheville and Spartanburg division of the Southern Railway, are popular summer and winter resorts.

Great expectations are entertained of the deposits of zircon in the valley of Green River.

The side streams flowing into Green River are mostly short, but have heavy falls. Whiteoak Creek is the only tributary of importance. Its fall, however, is small, but it has a very wide flood plain. The bottom land is well cultivated, mostly in corn. The soil is loamy and rich. The average fall is about 12 feet to the mile; the average annual fluctuation 10 feet.

FALLS ON UPPER CATAWBA RIVER, NORTH CAROLINA.

CATAWBA RIVER.

PHYSICAL FEATURES.

This river rises near the Buncombe and McDowell county line in North Carolina, and flows almost due east through McDowell and Burke counties and between Alexander and Catawba counties, where it turns to the south and finally enters South Carolina near the Mecklenburg-Gaston-York county line. After a course of about 160 miles in South Carolina it joins the Congaree to form the Santee. Below the mouth of Big Wateree Creek the river is known as Wateree River. Its drainage area in North Carolina is 3,085 square miles. Its total drainage area is 5,225 square miles.

The Catawba receives its headwaters from the southeastern slopes of the Blue Ridge, the main stream rising at the junction of the latter mountains with a spur known as the Edmondson Mountains. At Oldfort the waters of Mill Creek, with its branch, Jarrett Creek, are added to the Catawba, forming a river of considerable size. The drainage basins of these streams are decidedly mountainous, with steep, wooded slopes. The streams are swift mountain torrents, with large falls and great fluctuations of discharge. The flow at times of low water, however, is fairly large. On Catawba River above Oldfort there are precipices many feet in height, over which the river plunges in its descent toward the Piedmont Plain. (See Pl. XXXV.) In the first 6 miles of its course the river falls 1,500 feet. Below Oldfort the character of the drainage basin changes, becoming very like that of the Yadkin, described on pages 158 to 164. The valley broadens out, especially on the south side of the river, the land immediately contiguous to the stream being flat or gently rolling. The Blue Ridge is not far distant, however, extending to the northeast, with frequent ridges projecting toward the Catawba, between which flow the numerous northern branches of the stream. The tributaries from the north are Curtis, Crib, Clear, and Buck creeks, North Fork, Paddy Creek, Linville River, Cane Creek, Upper Creek, John River, and Lower Creek. These streams for the most part receive their waters from either the Blue Ridge or the Linville mountains, and in their upper courses run between parallel ridges with steep slopes heavily wooded. In their lower courses they reach the Piedmont Plain, where the fall becomes less and their valleys more open, being generally cultivated to some extent.

The river receives several tributaries from the south between the source of the stream and Morganton. The chief of these are Crooked Creek, Muddy Creek, and Silver Creek, meandering, comparatively slow-flowing streams, with a large part of their drainage areas under cultivation.

The reconnaissance of the drainage basin of Catawba River extended only from its headwaters to Morganton, N. C., that being the portion of greatest interest in connection with the studies of the proposed Southern Appalachian Park. Below Morganton the river receives a number of large tributaries and has many water powers in its course across the Piedmont Plain, but they were not visited.

RAINFALL.

The average rainfall in the basin of the Catawba is about 50 inches, distributed as follows: Spring, 12 inches; summer, 14 inches; autumn, 10 inches; and winter, 14 inches. Toward the upper part of the stream, however, the rainfall in winter increases, and is probably greater than in summer.

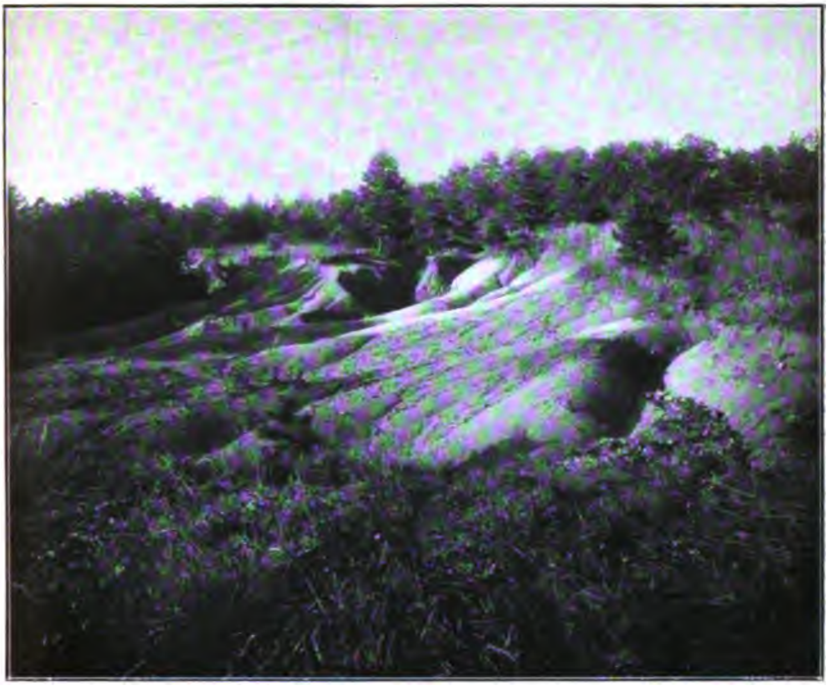
FORESTS.

The region of the headwaters of the Catawba and its chief branches, which flow from the steep slopes of the Blue Ridge, is heavily forested. At the foot of the mountains the timber consists of beech, poplar, linn, oak, and ash, changing to pines as the slopes are ascended, and near the summits to balsam fir. In the broad valley of the main stream a large part of the land has been cleared and is now used for agricultural purposes. The soil is deep and fertile, the top soil being largely flood deposits of the river. When the forests are cleared from the bases of the steeper mountain slopes considerable difficulty is experienced from the washing away of the top soil, leaving only the barren subsoil or clay beneath. This wash is often so extensive as to completely destroy large areas of land. Pl. XXXVI shows the effect of deforesting areas which can not properly be protected from this agency.

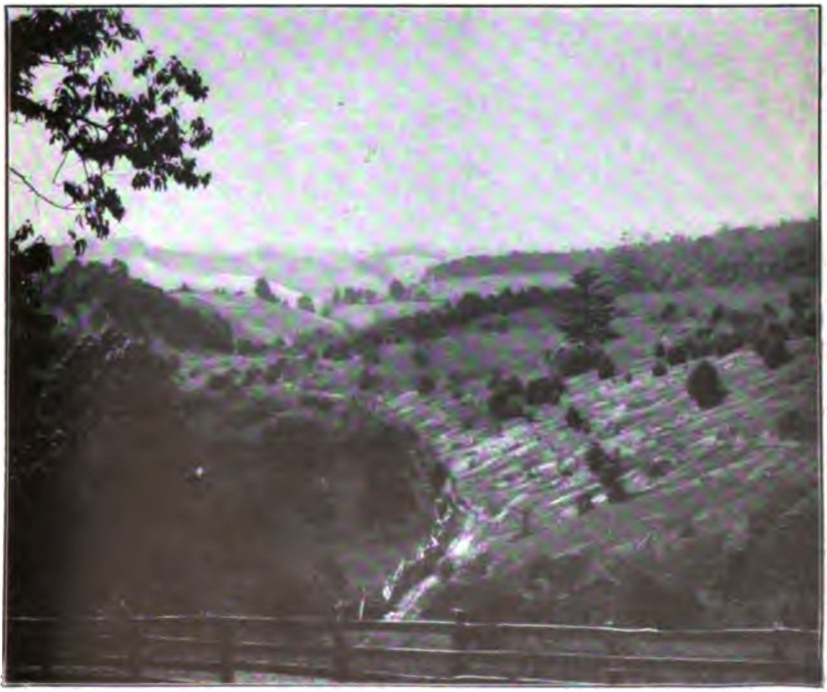
The banks of the Catawba are subject to overflow during the highest floods, and great damage is often caused. It is not uncommon for a fine stretch of farming land to be completely ruined in a single day by the high waters washing away the soil down to the bottom clays or gravels. (See Pl. XXXVII, *A*.) It has been estimated that in the drainage basin of the Catawba a single flood has caused damage to the extent of a million dollars. (See Pl. XXXVII, *B*.) That these floods are checked to some extent by the forests there can be no doubt; and in the absence of other regulators, such as lakes or marshes, the forests on the mountain sides form the only protection that the people dwelling in the valleys below have from the violence of flood waters.

DISCHARGE MEASUREMENTS.

During the investigation temporary gaging stations were established on Catawba River near Morganton, on John River near Morganton, and on Linville River near Bridgewater. For several years the

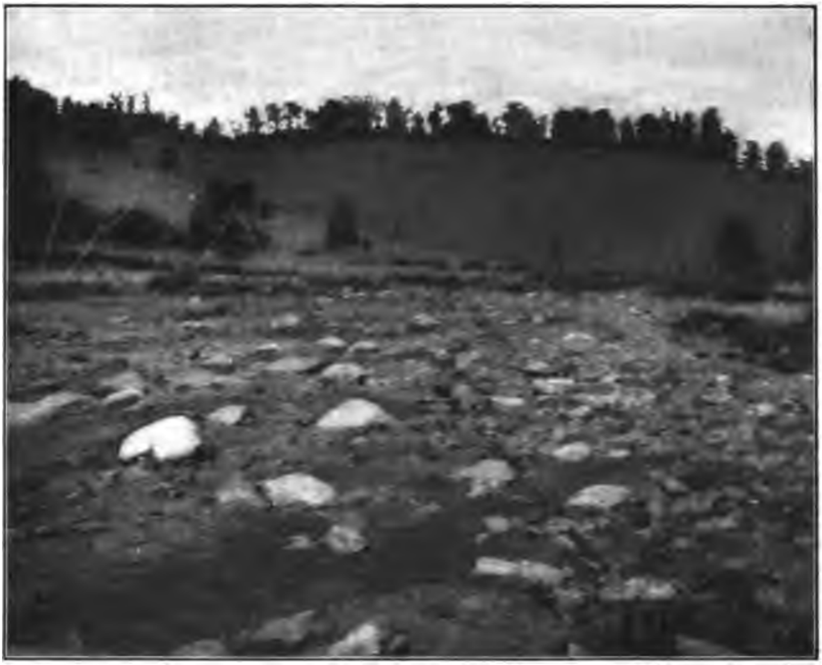


A.

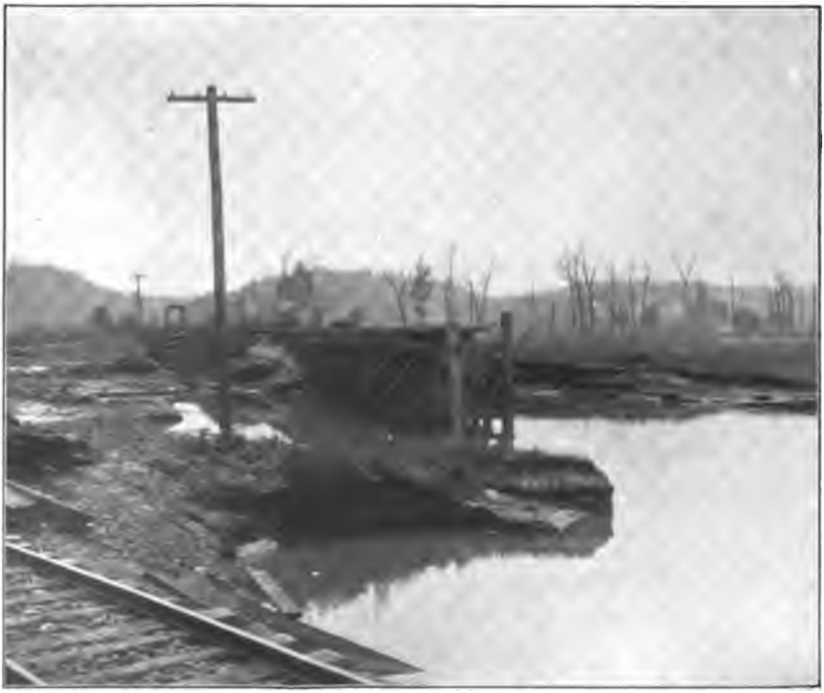


B.

VIEWS SHOWING HILLSIDE WASH IN VALLEY OF CATAWBA RIVER.



A. VIEW SHOWING REMOVAL OF SOIL IN VALLEY BY FLOODS.



B. VIEW IN VALLEY OF CATAWBA RIVER, SHOWING DESTRUCTION BY FLOODS.

Survey has maintained two stations on the Catawba River—one at Catawba, N. C., and the other at Rockhill, S. C.—the results of which have been published in the annual reports. The results of all measurements made on the river during the investigation are contained in the following table; the results of measurements on the tributaries in the table on pages 151 and 152.

Discharge measurements of Catawba River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
Feb. 21	Rockhill, S. C	E. W. Myers	2.63	3,803
Feb. 22	do	do	5.28	16,791
Apr. 13	do	do	2.75	4,703
Apr. 21	do	do	9.07	31,610
May 21	do	do	2.42	3,703
July 4	do	do	2.86	5,623
Aug. 16	do	do	1.70	1,936
Oct. 26	do	do	3.30	8,843
1901.				
Apr. 4	do	do	9.80	33,150
Apr. 23	do	do	4.65	10,314
May 23	do	do	[a]24.15	150,783
July 20	do	do	2.00	3,822
1900.				
July 3	Catawba, N. C	do	3.45	3,372
Aug. 14	do	do	2.10	914
Nov. 7	do	do	2.95	2,083
Dec. 18	do	do	2.59	2,139
1901.				
Mar. 29	do	N. C. Curtis	5.83	5,640
Apr. 27	do	E. W. Myers	4.37	4,354
July 25	do	do	2.95	2,805
1900.				
June 13	Near Morganton, N. C		1.33	1,393
June 18	do		2.50	4,030
July 6	do		1.30	1,164
Aug. 8	do		0.60	558
Sept. 24	do		0.50	525
Nov. 7	do		1.50	1,374
June 28	Oldfort, N. C	H. A. Pressey	10.10	53
Aug. 20	do	N. C. Curtis	12.70	11
Sept. 20	do	do	12.78	12

[a] Greatest flood ever known on river.

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of all the measurements in the above table except those made at Oldfort, where a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter case, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The following table, computed by E. W. Myers, shows the comparative minimum flows of Catawba River at the Catawba and Rockhill stations, which are about 60 miles apart, for the years 1895 to 1899. The drainage area at Catawba is 1,535 square miles and at Rockhill 2,987 square miles. Comparing this table with a similar one for Yadkin River, published in Water-Supply Paper No. 36, page 119, it will be seen that the run-off per square mile does not vary more than would be expected. The Catawba station was established in 1896, the Rockhill station in 1895.

Table showing comparative minimum flows of Catawba River at gaging stations at Catawba, N. C., and at Rockhill, S. C.

Year.	Driest month.		Mean flow for driest month.		Mean flow per square mile for driest month.		Minimum flow for year.		Minimum flow per square mile for the year.	
	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.
			Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1895	Sept[a]	....	1,318	....	0.441	....	1,300	....	0.435	....
1896	Aug	Oct.	1,604	865	.54	0.56	[b]1,330	770	.445	0.501
1897	Sept.	Sept.	1,817	1,017	.61	.66	[c]1,575	[d]850	.528	.553
1898	June	June	2,091	1,069	.70	.69	1,600	910	.535	.592
1899	Nov	Nov	2,492	1,340	.835	.873	2,300	1,220	.770	.793

[a] Seven days' record.

[b] Also in July, August, and September.

[c] Minimum occurred in January. September minimum was 1,700 second-feet, or 0.569 second-foot per square mile.

[d] Minimum in October. September minimum 900 second-feet, or 0.579 second-foot per square mile.

WATER POWERS.

Between Morganton and the mouth of Mill Creek, a distance of 50 miles, there are 197 shoals with an average fall of about 2 feet. In McDowell County the fall of the river is very great, there being in one or two cases vertical drops of 100 feet, but the channel is so narrow that the power is not of great value for development. Rock Ford Shoal, at Morganton, has a natural fall of 9½ feet in a distance of about 1,500 feet.

Although the investigation embraced only the portion of the drainage basin above Morganton, as some of the chief water powers of the river are below that place they will be mentioned in this connection. Briefly described, they are as follows:

Devil Shoal has a fall of 14 feet in a distance of 1 mile, and is well located for improvement. Horseford Shoal, 3 miles north of Hickory, has a fall of 31 feet in 2.9 miles; the power is utilized to only a limited extent. The Great Fall Shoals have a fall of 14.8 feet in a distance of 1 mile. Canoe Landing Shoal, about 2 miles above the mouth of Lower Little River, has a fall of 8.9 feet in a distance of 1.87 miles. The Lower Little River Shoals are between the upper end of Druin Island and the lower end of Three-Cornered Island, with a fall of 9.7 feet in a distance of 1.16 miles. Lookout Shoal, about 6 miles above Catawba Station, has the greatest fall of any shoal on the river in North Carolina, the descent being 54.25 feet in a distance of 3.2 miles. About 30 feet of this fall is said to occur in a distance of three-fourths of a mile. The Buffalo Shoals have a fall of 11.4 feet in a little more than a half mile; they are a short distance below the Western North Carolina Railroad crossing. Long Island Shoal, about 7 miles southeast of Catawba Station, has been improved and a cotton factory constructed to utilize the power. Monbo Shoal is utilized by a cotton mill. Beatties Ford Shoal has a fall of 13 feet in 2.38 miles, and

Cowan Ford Shoal a fall of 27 feet in a distance of 4.17 miles. Mountain Island Shoal is utilized to a small extent by a cotton factory containing 6,300 spindles and using a fall of 22.5 feet. Tuckasegee Shoal, about 9 miles above the State line, has a natural fall of 11 feet in a distance of 1 mile, and is utilized by a cotton mill of 6,000 spindles. Near the State line there are several shoals with falls of from 3 to 5 feet, some of which have been used to a limited extent, but considerable difficulty has been experienced from high water.

TRIBUTARIES OF CATAWBA RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the important tributaries of the Catawba above Morganton, N. C., in order downstream:

Discharge measurements of tributaries of Catawba River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 28	Mill Creek	Oldfort	H. A. Pressey	3.85	85.0
Aug. 20	do	do	N. C. Curtis	6.73	27.0
Sept. 20	do	do	do		13.0
June 28	Jarrett Creek	Near Oldfort	H. A. Pressey		17.0
Do	Curtis Creek	200 feet above ford of Oldfort road.	do		82.11
Aug. 20	do	do	N. C. Curtis		16.50
June 28	Crib Creek	Near ford of main road	H. A. Pressey	4.9	28.03
Aug. 28	do	do	N. C. Curtis		10.0
June 28	Clear Creek	200 feet above ford of main road.	H. A. Pressey		25.25
Aug. 28	do	do	N. C. Curtis		12.0
June 14	Buck Creek	½ mile above mouth, at main ford.	H. A. Pressey		51.91
Aug. 20	do	do	N. C. Curtis	5.35	41.4
July 3	North Fork of Catawba River.	First ford above mouth	H. A. Pressey		240.2
Aug. 18	do	do	N. C. Curtis		67.3
Sept. 21	do	do	do	3.18	61.69
June 15	Turkey Cove Creek	Just above second ford	L. V. Branch	5.75	21.48
June 26	do	do	do	5.30	164.8
June 14	Muddy Creek	Bridgewater	H. A. Pressey	5.80	161.9
June 16	do	do	L. V. Branch	4.1	618.0
July 10	do	do	do	6.0	119.2
Aug. 17	do	do	N. C. Curtis	6.43	98.6
Sept. 21	do	do	do	6.34	101.7
June 14	Paddy Creek	Near Bridgewater	H. A. Pressey	11.3	19.78
June 16	do	do	L. V. Branch	5.4	203.67
July 10	do	do	do	11.55	11.5
Aug. 17	do	do	N. C. Curtis	12.35	7.0
June 21	Linville River	Linville	H. A. Pressey	14.83	21.0
June 24	do	do	do	14.23	90.22
June 14	do	Near Bridgewater		9.92	104.0
July 3	do	do		9.54	216.0
July 10	do	do		9.90	116.0
Aug. 17	do	do		10.15	78.0
Sept 21	do	do		9.8	55.0
June 14	Cane Creek	Lowest ford of main Morganton road.	H. A. Pressey	5.72	18.58
June 18	do	do	L. V. Branch	5.85	28.45
Aug. 17	do	do	N. C. Curtis	6.3	7.2
June 14	Silver Creek	Near Morganton	L. V. Branch	6.84	124.0
Aug. 10	do	do	N. C. Curtis	8.30	48.4
Sept. 24	do	do	do	8.20	56.0
1901.					
June 14	do	do	E. W. Myers	13.08	995.0

Discharge measurements of tributaries of Catawba River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 13	Upper Creek	½ mile above mouth	N. C. Curtis	2.2	182.4
July 6	do	do	L. V. Branch	2.3	50.0
Aug. 8	do	do	N. C. Curtis		85.05
Sept. 24	do	do	do		60.0
June 20	do	Ford at Henderson's mill	H. A. Pressey	12.9	20.42
Do.	do	Upper Creek Falls	do		27.0
Do.	Steel Creek	Footbridge 100 yards above mouth.	do	3.20	100.21
Sept. 25	John River	Collettsville	N. C. Curtis	4.77	40.0
Nov. 6	do	do	do	4.47	135.0
June 13	do	Near Morganton		2.64	465.0
June 19	do	do		8.50	1,202.0
July 6	do	do		2.63	511.0
Aug. 8	do	do		1.90	135.0
Sept. 24	do	do		1.90	148.0
Nov. 7	do	do		2.32	367.0
Sept. 25	Mulberry Creek	At mouth	N. C. Curtis	7.85	17.0
Nov. 6	do	do	do	7.95	39.0
Do.	Wilson Creek	do	do	0.75	208.0
June 13	Lower Creek	2 miles above mouth	E. W. Myers	14.58	209.0
July 6	do	do	L. V. Branch		132.0
Aug. 8	do	do	N. C. Curtis		69.0
Sept. 24	do	do	do	15.38	56.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in above table of John River near Morganton and of Linville River near Bridgewater. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The principal tributary drainage basins and water powers are briefly described on the following pages.

CENTER, CRIB, AND CLEAR CREEKS.

Of the tributaries from the north, Center, Crib, and Clear creeks have drainage areas of a similar character. There is considerable fall near their sources, which gradually becomes less as the streams are descended, the valleys broadening out and being partially cultivated. About three-fourths of the drainage areas are forest-covered. The streams are too small for extensive water-power development, but two small gristmills have been built on Crib Creek. The low-water flow of the stream is so small, however, that the mill can not be run during the dry season.

BUCK CREEK.

This creek rises in Buck Creek Gap, and has a drainage basin similar to the creeks just described, though much larger. The fall is very great along its upper course. Six miles from its mouth are the falls of Buck Creek, with a vertical drop of 12 feet. A rough and rocky highway, leading from Marion through Yancey County, follows the stream throughout its course. The scenery near the gap is very fine. Two mills have been constructed, and are run during a part of the year. Near the mouth of the creek there are some good farms. About a quarter of a mile above the mouth the Marion-Oldfort road crosses the creek. Here measurements were made of the discharge (see table on page 151).

NORTH FORK OF CATAWBA RIVER.

This stream enters the Catawba near Marion. At its headwaters it is a mountain stream with very heavy fall, draining the narrow valley between the Blue Ridge and the Linville mountains. The mountain slopes are covered with a valuable growth of timber, practically no cutting having been done on them. About 7 miles downstream the valley broadens slightly and furnishes a very fertile soil excellent for agricultural purposes. This valley land has been cleared and is now largely in grain or grass. About three-fourths of the drainage area is still in forest. Two small combined gristmills and sawmills have been built on the stream, with falls of 6 and 8 feet. Turkey Cove Creek, a branch of the North Fork, is a mountain stream of considerable fall, with wooded slopes. The total drainage area of the North Fork is 835 square miles.

PADDY CREEK.

This creek has the same general characteristics as the other northern tributaries of the Catawba in the region. Its headwaters are on the steep slopes of the Linville Mountains, and its lower course is across the Catawba Valley. Its watershed is long and narrow, being close to Linville River on one side and flowing nearly parallel to the Catawba on the other.

LINVILLE RIVER.

This river is formed by a number of small streams which head on Grandfather and Sugar mountains and in Linville Gap. The sources of most of the streams are large springs, which are numerous throughout the region, furnishing perfectly clear and chemically pure water. Grandfather Mountain has an elevation of 5,964 feet; the heads of most of the streams rising upon its slopes are at an elevation of 5,000 feet. The elevation of Sugar Mountain is 5,289 feet, while Linville Gap, between these two high peaks, has an elevation of 4,097 feet. Four miles south of Grandfather Mountain is Grandmother Mountain, elevation 4,686 feet, upon which rises Grandmother Creek, which flows into Linville River 1 mile below the village of Linville.

The mountain slopes are steep and rocky, the small streams falling in a series of cascades. The virgin growth of timber is still on the mountain sides and extends to the summits, practically no cutting having been done. Three miles below Linville, at Pineola, there is a healthy growth of white pine, but from Linville upstream the river is above the white-pine belt, the growth changing to spruce, chestnut, white and red oak, poplar, linn, ash, buckeye, birch, beech, cherry, and, on the highest elevations, balsam fir. The temperature is usually low, frosts having been known to occur in each month of the year.

Below Grandmother Creek the river has no tributaries of any size. From Grandfather Mountain to Linville Falls its valley is narrow, the land on both banks rising abruptly to the mountain summits, permitting only short tributaries and a narrow drainage area. Linville, a village of about thirteen houses and a summer hotel, is between the river and Grandmother Creek, on a comparatively flat area, and Pineola, 3 miles below, a village built up largely during 1900, occupies another flat section.

The falls of the Linville, located near the Mitchell-Caldwell-McDowell County line, have an aggregate fall of 90 feet in four clear leaps. The first fall is 50 feet upstream from the main fall, and is a vertical drop of 15 feet. There are then three drops in quick succession of 25, 10, and 40 feet, respectively. The water at the last drop (see Pl. XXXVIII) falls in one sheet into a still pool, from which it flows through a narrow gorge 10 miles long between Gingercake Mountain, Hawks Bill, Table Rock, and Shortoff Mountain on the east and the Linville Mountains on the west. The walls of this gorge are precipitous, in many places almost vertical, and rise to heights of from 500 to 2,000 feet. Through it the Linville has no tributaries, receiving only the water which falls on the steep slopes and the flow from the springs on the mountain sides. It may well be considered one of the greatest mountain features of the region. The high and rocky walls are so close to the river that there is no space for highway or railroad. In fact it is with the greatest difficulty that one can make his way through the chasm, jumping from rock to rock, clinging to rocky ledges, and in places where no foothold is offered on either side wading the stream. The scene is grand and inspiring, viewed either from the chasm, where immense vertical rocky cliffs rise on either hand, showing nothing beyond but the blue sky, or from the upper edge of the gorge, where one can look vertically down several hundred feet and see the rapid, sinuous stream cutting its way to the valley below.

At Linville Falls, at the upper end of the chasm, the drainage basin of the main stream and its tributaries has an area of 50 square miles. The next 10 miles of the course of the river is through the gorge. After emerging from the rocky walls of the chasm it flows for 8 or 9 miles as a comparatively quiet stream through Birch Bottom and Catawba Valley, finally joining its waters to Catawba River.

At Linville records of rainfall have been kept by the United States Weather Bureau for nearly eight years. These records show that the annual precipitation is about 46 inches, distributed as follows: Spring, 11.50 inches; summer, 13.50 inches; autumn, 9.50 inches; and winter, 11.50 inches. The climate is pleasant and very healthful, so that

LOWER FALLS OF LINVILLE RIVER, NORTH CAROLINA.

numerous summer visitors take advantage of the excellent hotel accommodations at Linville, at the foot of Grandfather Mountain.

There are opportunities for development of water power on the Linville and its tributaries. On Grandmother Creek the Linville Improvement Company has built a timber-crib dam across the stream near its mouth, to form a fish and ice pond. The dam is 20 feet high, but its height could be increased and a small water-power plant installed. There is another site farther up the creek where a fall of 15 or 20 feet could be developed.

At Linville Falls, on the main stream, at the head of the gorge, considerable power could be developed, though the chasm is so narrow that there would be difficulty in finding space for buildings. From Linville Falls to the point where the river enters the flat plain of the Catawba Valley the fall of the river is large, with frequent drops of 3 or 4 feet. About 2 miles below Linville Falls, near Bynums Bluff, there is a fall of 5 feet, and 1½ miles farther down is what is known as Cascade Rock, where the river falls vertically 12 feet. From the foot of the falls to the Catawba Valley the fall of the river is about 1,800 feet. None of the power in the gorge or at the falls has been developed.

There are several small mills on the river. One mile above Linville there is a small sawmill and gristmill with an 8-foot timber dam, which has sufficient water to run throughout the year. Two miles above Linville Falls, at the mouth of Camp Creek, there is a sawmill and gristmill utilizing an 8-foot fall, and 1 mile above the falls there is a sawmill with a timber dam 10 feet high, a 46-inch turbine being used to run a circular saw. At the Franklin mill, a half mile above the falls, Pine Creek has a 10-foot fall, and power is furnished by overshot wheels and turbines. About 4 miles above the mouth of the river, at Berry's mill, an 11-foot head is utilized with a 4-foot homemade wheel, and 3½ miles lower down, at Pool's mill, a 9-foot fall is utilized for a gristmill run by a 20-inch and a 36-inch wheel. On July 3, 1900, a gage was established at the latter mill, and the miller reads the height of the river every day. Measurements of flow have also been made, the results of which are given in the table on page 151.

In ordinary years the river has a fluctuation of about 8 feet at Pool's mill, though on September 6 and 7, 1898, the water rose 18 feet in forty-eight hours. This is the highest stage known, but in 1882 there was a rise of about 17 feet.

CANE CREEK.

Cane Creek, flowing into the Catawba from the north, drains 16 square miles of comparatively flat and open country, much of which is under cultivation. There is very little fall in this stream. The measurements made are given in the table on page 151.

UPPER CREEK.

This stream, the next important tributary of the Catawba from the north, rises on Jonas Ridge and Cranberry, Cold, and Park mountains, at an elevation of about 4,000 feet. The sides of these mountains are for the most part steep and precipitous and are covered with a dense forest growth. The most common trees are chestnut, oak, white pine, and poplar. Very little of the original timber has been cut, though fires have spread over considerable areas, seriously injuring the forests. As the fires, however, were widely separated, both in time and in area, the drainage basin near the headwaters of the stream is almost entirely forest covered, either with the original timber or with a younger forest growth.

A large part of the regular flow of the creek is made up of effluents from springs, which are numerous on the mountain slopes. To this flow, however, is added the surface drainage from the mountain sides, which in the upper part of the creek reaches the stream quickly, so that during a rain the creek rises rapidly and falls soon after the rain ceases.

Throughout this and the neighboring watersheds will be found shady ravines, with springs breaking forth and adding their waters to other springs until a considerable stream is formed with a comparatively constant flow. The Piedmont Springs, 9 miles from the source of Upper Creek, have been celebrated for thirty years, and formerly many people from the Southern States visited them as a summer resort, being accommodated in a large hotel close at hand. The springs are charged with iron and soda. Though still flowing, they are not now much visited and the hotel has fallen into decay. About 2½ miles from the source of Upper Creek is Cold Water Spring, where a hotel has recently been built to accommodate summer visitors.

The fall of Upper Creek and its tributaries is very great from the headwaters down to Piedmont Springs. The two forks of the creek have a fall of 250 feet per mile to their junction. In the next mile there is a fall of 1,000 feet, largely made up of a series of small falls of from 5 to 10 feet. About one-fourth of a mile below the Cold Spring hotel there is a single fall of 90 feet. On June 20, 1900, the stream was measured a few feet above these falls, and the quantity flowing was found to be 27 second-feet. The low-water flow is probably about two-thirds that amount. The walls here are steep and rocky, with good natural abutments for a dam, though the fall is so great that the storage capacity would not be very large. About three-fourths of a mile above these falls there is a combined shingle mill, sawmill, and gristmill. An 8-foot dam has been built across the stream, giving an 18-foot head on the wheel—a Smith-Morgan turbine. A half mile farther down there is another small sawmill and gristmill. Between the main falls of Upper Creek and the gristmill there is a fall of at least 200 feet in a distance of three-fourths of a mile.

The low-water flow of the creek is quite large, owing to the many springs in its watershed and to its forested basin. From Jonas Ridge down to Joy the drainage area is completely covered with forest from the river bank to the summits of the mountains. The most common trees are chestnut-oak, white pine, and poplar. At Joy there is a small gristmill with a 6-foot timber dam, and a half mile below there is a gristmill and sawmill with a flow of about 8 feet over a timber dam, two 36-inch turbines furnishing the power. There is another gristmill on Upper Creek near the mouth of Irish Creek. From Joy to the mouth of Upper Creek the valley is wider and the hills bordering the watershed are comparatively low and flat, rising on either side about 100 feet above the stream. The hillsides are largely covered with forests, the growth extending to the banks of the creek. There are, however, open cultivated areas through the valley, the chief crops being corn and wheat. It is probable that two-thirds of the total drainage area of Upper Creek is forested.

Below Joy there are two mills—Turner's and Wakefield's. In the next mile there is a fall of about 25 feet, the ordinary high-water rise above the present stage being about 7 feet. Turner's mill is a gristmill and sawmill with a fall of about 8 feet, two 36-inch Smith-Morgan turbines being used. The 7-foot dam backs the water about a quarter of a mile. At lowest stages the water is about 6 inches lower than at the time of measurement, when the discharge was 20.42 second-feet. In 1898 there was unusually high water, the stream rising 16 feet. Three miles below Turner's mill is Caldwell's gristmill, owned by Mrs. W. C. Anderson. There is a fall of 7½ feet here and backwater for 1 mile. There is said to be 14 horsepower available with one Smith-Morgan turbine 20 inches in diameter. At lowest stages the stream at this point falls about 4 inches below the surface elevation at the time of measurement, and at such times it has about one-third less flow. During high-water periods the rise is about 6 feet. The highest water known was about 12 feet above the surface elevation at the time of measurement.

Steel Creek.—This tributary of Upper Creek, which rises on Hawks Bill and neighboring mountains, enters the latter creek near Joy. Its drainage area has the same general characteristics as that of the upper part of Upper Creek, and its fall will average 530 feet per mile for the first 3 miles, 200 feet per mile for the next 2 miles, and 50 feet per mile the rest of the way.

JOHN RIVER.

John River, the largest tributary of the Catawba, adds its water to the latter stream about 3 miles northeast of Morganton. Its drainage area contains 213 square miles and is extremely rough and mountainous in its upper part, the topography becoming gradually more gentle as the river is descended. It receives its headwaters from the many fine, large springs and the run-off on Grandfather Mountain and the other mountains in the region near Blowing Rock.

This drainage basin, with its fine views, its dense forests, its numerous springs, and its salubrious climate, is one of the most beautiful and delightful parts of the Southern Appalachian region. The many summer guests at the hotels at Blowing Rock and Linville are well repaid for their visit by a day spent on the summit of Grandfather Mountain, from which is obtained a most magnificent view of the great billowy sea of mountains stretching away from it in every direction. A ride over the Yonahlossee road, the finest mountain road in the South, with its frequent glimpses of river valleys and mountain peaks beyond, with its numerous little streams which dash down the mountain sides, cross the road, and leap from rock to rock in their descent to join John River or one of their tributaries far below, is a pleasure to be long remembered.

The main stream and its upper tributaries, chief among which are Mulberry and Wilson creeks, have falls of 2,000 or 3,000 feet in the first few miles of their courses. Vertical falls are frequent, especially on Wilson Creek, and considerable power could be developed. Above Collettsville, at the junction of Mulberry Creek with John River, the drainage area is rough, the valley narrow, and the mountain slopes steep and well timbered. Below the junction the valley widens considerably, and where cleared of trees it presents a splendid farming country. There are great tracts, however, which are still in timber. On the ridge to the west of the river there has been considerable prospecting for gold, and a plan has been considered of constructing a flume to carry water from Wilson Creek across John River for use in hydraulic mining.

LOWER CREEK.

Lower Creek, the next tributary of the Catawba from the north, has a comparatively flat watershed. The fall is not so great as that of the upper branches, and in every way the creek has more the nature of a stream of the Piedmont Plain.

YADKIN RIVER.

PHYSICAL FEATURES.

Yadkin River rises on the eastern slopes of the Blue Ridge, in Caldwell and Watauga counties, near Blowing Rock, N. C. Its course is almost south, until at Patterson it turns to the northeast. It was examined and gagings were made as far down as Ararat River, a large tributary from the north. In this portion of its course it flows through Caldwell and Wilkes counties and between Yadkin and Surry counties.

Beginning at Siloam, where the flood plain of the river is about three-fourths of a mile wide, the bottom land gradually widens as the head of the stream is approached, being in some places nearly 2 miles in width. The flood plain is subject to occasional overflows. Its soil is very deep and fertile, the result of washings from the mountain slopes above. The river basin between Patterson and Siloam varies in width from 5 to 25 miles. The divides which separate it from the basins of the New and the Catawba are high and steep, so that the tributary streams are not very long, but they have large falls. On the north the river is flanked by the Blue Ridge, whose highest peaks attain elevations of more than 4,000 feet. On the south, and lying closer to the stream, are the Brushy Mountains, a low ridge which in places attains an elevation of 2,000 feet.

The upper part of the valley of the Yadkin is very well wooded, and the forests, with the deep soil on the mountain sides, tend to make the flow of the stream more constant than might be expected in the absence of lakes or marshes to act as regulators. The highest flood of which there is any record extant was in 1878, when the river rose 23 feet. The floods are of short duration, generally subsiding in from thirty-six to forty-eight hours. It is said that twenty-five years ago high floods very rarely occurred, and their frequency now is accounted for by the clearing of the hills and the removal of obstructions from the river.[a] The lowlands are more frequently overflowed than formerly, and more damage is done to the crops. The annual rainfall in the upper valley varies from 44 to 50 inches.

Between Patterson and Wilkesboro the lowlands are in places a mile or more in width and are exceedingly fertile. This region is known as Happy Valley, and is considered to be among the finest agricultural sections of the State. The chief products are corn, wheat, tobacco, cotton, cane, and fruits. The corn and wheat raised are especially good. Pasture land in the immediate vicinity is poor, but along the slopes of the Blue Ridge grazing is better and considerable hay is produced. The climate is salubrious. The Wilkesboro division of the Southern Railway passes up the north banks of the Yadkin as far as the town of North Wilkesboro. The only two towns of any importance along this part of the stream are Elkin and Wilkesboro. Both are growing rapidly and give promise of continual development.

The well-defined river basin of the Yadkin is marked by an apparently unbroken valley floor lying at an average elevation of 1,200 feet. This floor, which rises by a gentle inclination from about 1,100 feet along the river to 1,400 feet at the bases of the bounding ranges, can be seen to best advantage when standing on the steeper slopes of the mountains, as, for instance, on the road from Lambsburg to Cold Spring, in the northern part of Surry County. As soon as one approaches the tributaries or the river itself, it is evident that the valley floor is not continuous, but that it has been deeply trenched by nearly all of the streams belonging to this portion of the Yadkin river system. The trench now occupied by the main river is from 300 feet to 400 feet below the general level of the valley, and varies in width from a half mile to a mile and a quarter. The width of the trench is clearly influenced by varying resistance in the rock series crossed by the stream; the depth, however, seems to increase uniformly downstream, without relation to rock resistance. The bottom of the main trench is covered with alluvial sands, gravels, loams, or clay to a depth of from 15 to 20 feet. Through the bottoms thus formed the river pursues a meandering course, being sunk about 10 feet below the general level of the valley floor at Siloam and not more than 5 feet below in the vicinity of Patterson's mill.

---

[a] Ann. Rept. Chief of Engineers U. S. A., 1878, p. 628.

The trenches cut by the tributary streams are narrower than the main trench, have steeper bounding slopes, which are sometimes precipitous, and have narrower bottoms, which often extend far up the streams. Near their mouths the tributary valleys are very narrow, their channels steep, and usually a number of low cascades over resistant layers characterize the debouchments of the streams upon the broader bottoms of the river.

Along the steep slopes of the trench of the main stream, and overlooking the lower bottoms, are two sets of river terraces, which have been partially cut out of the deeply decayed gneissic rocks and partially built up of stratified gravels, sands, and clays. These two terraces are at elevations of 20 and 60 feet above the lower bottoms. In places traces of a third terrace, at about 100 feet, can be seen. Deposits similar in character and form can be found in the tributary gorges, usually at the 100-foot elevation.

SOILS.

In general the rocks of the region are schists of moderate compactness, with gneissic and slaty bands in the vicinity of Blowing Rock. Near Mount Airy the metamorphic crystallines seem to have been cut by compact granitic rocks, which withstand weathering much better than the surrounding formation, and thus have formed low hills standing above the general level (1,200 feet) of the valley floor. The granitic rocks on disintegrating produce clays and sands; but the areas covered by the resulting soils are small. The metamorphic rocks generally produce clayey subsoils, with a not very porous top soil. In some localities an unusual amount of quartz in the rocks has resulted in the production of sandy soils. Thus the soils of the valley floor are generally rather heavy, with an impervious subsoil. Consequently neither heavy rains nor the average moderate precipitation penetrates to a great depth. Instead the water gathers into surface rills and rapidly finds its way into the streams, at the same time carrying with it a large portion of the looser surface soil.

The nearly level elevated valley floor has been almost wholly cleared of timber. In it areas of remarkable fertility occur at intervals. These have been extended in size and in depth by the wash from the mountain sides. The soil of the slopes on the north side of the stream is largely siliceous and is well mixed with humus and vegetable mold, affording rich pasture and farm lands. The soil of the mountain slopes on the south side of the river is shallow and comparatively poor.

FORESTS.

The forest growth consists chiefly of oak, chestnut, poplar, and linn, with some pine, and with occasional patches of hemlock. Near the railroad considerable cutting of the best trees has been done, but in many parts of the area the timber is practically untouched. Considerable damage has also been caused by forest fires, though in most places the injury from this cause has not been serious or permanent.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the river at various localities along its course:

Discharge measurements of Yadkin River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
June 20	Second ford below Patterson's mill	N. C. Curtis and Cleveland Abbe, jr.	13.30	182.0
July 14	do	do	13.50	100.3
Aug. 7	do	do	13.40	76.2
Sept. 26	do	do	13.53	43.0
June 21	Wilkesboro	do	26.73	780.0
June 23	do	do	26.14	1,737.0
July 4	do	do	26.83	663.0
July 12	do	do	27.05	488.2
Aug. 6	do	do	27.20	386.0
Oct. 1	do	do	27.20	369.1
Nov. 4	do	do	26.22	1,331.0
1901.				
June 8	do	do	25.81	1,762.0
June 14	do	do	16.50	11,667.0
June 15	do	do	14.22	12,582.0
June 18	do	do	23.80	3,727.0
1900.				
July 11	Siloam	do	2.90	1,367.0
Aug. 3	do	do	2.60	1,218.0
Oct. 31	do	do	3.10	1,469.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table at Siloam. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

For several years the Survey has maintained a gaging station on Yadkin River at Salisbury, also one at Norwood, both farther downstream than the present investigation extended, the results of which have been published in the annual reports. The station at Norwood was discontinued in January, 1900.

WATER POWERS.

Between Patterson's mill and the town of Patterson, about 4 miles farther upstream, Yadkin River is a meandering stream, with slight fall, occupying a wide, terraced trench about 80 feet below the general level of the trenched valley floor already described. Although there are many shoals with gravelly bottoms between Patterson and the mouth of Little Ararat River, there are no good water powers, because of the broad, alluvium-lined valley, which offers no anchorage for dams; nor are there any sharp falls or even important rapids sufficiently high to furnish useful power. About 1 mile above Brown's ford, 4 miles west of Wilkesboro, what seem to be gravelly shoals in the river accompany a fall in the channel of 5 feet within a quarter of a mile. The bottom lands on the north bank of the river at this place are only 200 feet wide. On the south side, however, they are somewhat wider and seem to afford poorer holding ground. Again, about 3 miles above Ronda the river runs at the bottom of a narrow, rock-ribbed trench, and its channel is cut across by rough ledges of hornblende-schist. This locality, with a channel fall of 5 or 6 feet, seems to be the best on the whole stretch of the main stream, having a good foundation for a dam and natural abutments.

There are no mills on the main stream between Patterson's mill and Siloam. At Patterson, 4 miles upstream from the mill mentioned, there are two mills. The first one, a cotton mill, has a fall of about 10 feet. The other one, a few hundred yards upstream, is a woolen factory operated during the greater part of the year by water power, but having an auxiliary steam plant for use during unusually low water. This mill uses a fall of 25 feet, obtained by sluicing the water 200 yards from a 15-foot dam.

Above Patterson the river occupies a narrow, rock-walled gorge, affording many good powers, though a number are at present inaccessible. About 1 mile above the woolen mill and sawmill just mentioned the whole volume of the river crosses Ripshin Mountain through a narrow water gap floored and flanked to a great height by firm gneiss and schist. The channel at this point has a drop of certainly 5 feet within half as many rods, and a dam 100 feet long and 10 feet wide would completely flood broad meadow lands to a distance of a mile upstream. About 1¼ miles upstream from this gap through Ripshin Mountain a small mill has been built to utilize a fall of 10 feet, and on Mill Fork, one-fourth mile above its confluence with the Yadkin, another mill, with an 8-foot fall, has been established, while about 1 mile above Kirby Gap this same stream (Mill Fork) has an almost perpendicular fall which is estimated to be 250 feet.

The following table contains interesting data regarding the elevation, fall, etc., of the river in various portions of its course above the mouth of Ararat River:

Elevation, fall, etc., of Yadkin River above Ararat River.

Place.	Distance from Siloam.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Average annual fluctuation.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Mouth of Ararat River		798				6
			50	130	2.6	
Wilkesboro	50	928				7
			32	322	10.06	
Patterson	82	1,250				5
			13	2,250	173.07	
Head of stream	95	3,500				

Above its junction with Mill Creek the river pursues a winding course, flowing at the bottom of a very deep and narrow gorge, with an average fall of about 50 feet to the mile.

Below Ararat River the valley of the Yadkin averages 50 miles in width, much of it composed of fertile bottom lands. At several places, however, the hills close in upon the river, confining it between steep and rocky banks. In this lower portion of its course there are many places where water power could economically be developed. The following table gives the locations of the principal powers:

Summary of water powers on Yadkin River.[a]

Locality.	Distance from State line.	Drainage area.	Total fall.		Gross horsehower available.			Remarks.
			Height.	Length of shoal.	Minimum.	Minimum average for the low season.	Average for the low season of average dry years.	
	Miles.	*Sq. mi.*	*Feet.*	*Feet.*				
Bluitts Falls	12.0	6,650	9.00	1,000	1,500	1,900	2,170	
Grassy Island Shoal	13.0	6,624	36.00	[b]4.5	5,970	7,600	8,680	
Swift Island Shoal	42.0	4,323	18.00	[b]2.5	1,942	2,476	2,796	
Gunsmith Shoal	57.5	4,300	9.50	2,500	1,020	1,300	1,470	
Narrows	60.0	3,938	91.00	[b]5	8,954	11,375	12,922	
Bull Island Shoal	65.0	3,800	29.00	[b]2	2,854	3,625	4,118	Undeveloped.
Penningtons Shoal	67.0	3,900	74.00	[b]4.5				
Milledgeville Shoal	70.0	3,500	14.00	[b]0.7	1,378	1,750	1,988	
Motts Falls	72.3	3,400	13.50	[b]0.8				Do.
Bald Mountain Shoal	73.8	3,300	8.50	[b]0.5				Do.
Flat Swamp Mountain Shoal.	78.3	3,000	10.20	[b]0.5				Do.
Fries Manufacturing and Power Co.	131.5	1,865	10.00	1,600				Rock bottom.
Langenhour & Neason's dam.	138.5	1,827	4.57		220	280	325	Do.
Shallow Ford Shoal	145.0	1,812	7.89	5,560	375	485	550	Rock and gravel bottom.
Shoal above Shores Island.	155.2	1,633	7.73	9,662	330	430	490	Do.
Bean Shoal (head)	164.7	1,521	39.17	[b]4	1,560	2,030	2,320	Rock bottom.
Lime Rock Shoal	169.3	1,165	10.62	[b]2.59	325	425	490	Do.
Shoal below Rockford	174.8	1,097	8.38	4,500	240	320	360	Do.
Seven Island Shoal	177.0	1,066	4.02	2,630	112	145	165	Do.
Long Shoal	182.0	949	11.18	[b]1.61	205	335	385	Do.
Woodruff Fishtrap Shoal.	185.0	925	4.55	1,800	105	134	155	Do.
Mitchell Island Shoal	186.6	925	4.00	2,740	90	115	135	Gravel bottom.
Swan Creek Shoal	196.7	739	5.40	3,160	100	125	145	Rock bottom.
Reeve Island Shoal	206.5	540	3.86	2,700	50	65	75	Rock and gravel bottom.
Blair Island Shoal	216.5	420	3.44	1,700	36	46	53	Gravel bottom.

[a] From Bull. No. 8, N. C. Geol. Survey.

[b] Miles.

It will be seen that the fall is not in the form of direct vertical drops, but in shoals of considerable length. One of the greatest drawbacks to the development of power in a large part of the Yadkin is the lack of proper means of transportation.

TRIBUTARIES OF YADKIN RIVER.

DISCHARGE MEASUREMENTS.

The following measurements were made of the important tributaries of the Yadkin to and including Ararat River, in order downstream:

Discharge measurements of upper tributaries of Yadkin River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 20	Elk Creek	One-fourth mile above ford	Cleveland Abbe, jr., and N. C. Curtis.	2.4	119.0
July 13	do	do	do	2.43	61.0
Aug. 6	do	do	do	2.60	37.0
Sept. 26	do	do	do	2.61	30.0
June 21	Stony Creek	Footbridge at Colberts	do	2.65	78.4
July 13	do	do	do	2.70	80.5
Aug. 6	do	do	do		50.0
Sept. 26	do	do	do	2.87	31.10
June 21	Louis Fork of Yadkin River.	Footbridge on Mount Pleasant road.	do	3.10	127.0
July 13	do	do	do	3.23	99.0
Aug. 6	do	do	do	3.30	69.0
Sept. 26	do	do	do	3.33	63.0
June 23	Reddie River	North Wilkesboro	do	24.73	218.1
July 12	do	do	do	25.15	98.1
Aug. 4	do	do	do		93.0
Oct. 1	do	do	do	25.25	60.2
June 23	Mulberry River	Trestle of Greensboro and Wilkesboro division of Southern R. R.	do	21.93	108.4
July 3	do	do	do	22.25	50.3
Aug. 4	do	do	do	22.50	39.25
Sept. 27	do	do	do	22.42	61.2
Nov. 2	do	do	do		55.0
June 25	Roaring River	Greensboro and Wilkesboro R. R. bridge.	do	23.68	520.2
July 9	do	do	do	25.45	161.4
Aug. 4	do	do	do	25.75	117.0
Sept. 27	do	do	do	25.13	109.0
Nov. 2	do	do	do	24.27	187.0
Sept. 27	Big Bugaboo Creek	Ford of road from Roaring River to Elkin.	do	1.28	30.0
June 25	Big Elkin River	Greensboro and Wilkesboro R. R. bridge.	do	24.53	65.0
July 9	do	do	do	25.95	29.0
Aug. 4	do	do	do		24.0
Sept. 27	do	do	do	26.22	27.0
June 26	Mitchell River	do	do	21.63	393.1
July 10	do	do	do	24.00	139.2
Aug. 3	do	do	do	24.25	119.0
Sept. 28	do	do	do	24.25	160.0
Nov. 1	do	do	do	23.89	216.0
June 26	Fisher River	Greensboro and Wilkesboro R. R. trestle.	do	20.93	549.0
July 10	do	do	do	23.38	172.0
Aug. 3	do	do	do	23.60	126.0
Sept. 28	do	do	do	23.72	119.0
Nov. 1	do	do	do	23.70	235.0
June 27	Ararat River	do	do	23.9	801.0
July 11	do	do	do	26.0	317.1
Aug. 2	do	do	do	26.25	265.44
Sept. 29	do	do	do	26.46	243.0
Oct. 31	do	do	do	25.66	307.0

NOTE. In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an crease in the gage height represents an increase in the discharge of the stream.

The drainage basins and water powers of the principal tributary streams are briefly described on the following pages. Practically all of the tributaries whose water powers are worth considering flow into the Yadkin from the north. The divides and spurs, between which are the basins of the tributary streams, are seldom more than a mile wide and form many picturesque coves and valleys.

ELK CREEK.

This stream was measured at a foot log about one-fourth of a mile above the road ford at Elkville. At the point of measurement and for a short distance above and below are cascades over broad ledges of gneiss, and the stream is bounded by steep, rocky slopes. The natural fall is estimated to be at least 10 feet within 200 yards. Higher up the stream there are undoubtedly other fair powers, but they were not examined.

STONY CREEK.

This stream enters the Yadkin from the north about 6 miles below Elkville, and possesses a splendid power at its mouth and for a short distance upstream. Throughout the last half mile of its course the banks are the steep, rocky sides of a narrow, V-shaped gorge. Within this distance the stream has an estimated fall of at least 50 feet, flowing over a series of ledges in falls or cascades of from 6 to 10 feet each. Just at the mouth of the creek there stands a combined sawmill and gristmill driven by turbine power. The dam is only 6 feet high, but is so favorably placed on ledges that about 18 feet head is obtained. This is an excellent mill site, but the road leading down to it from the surrounding country is poor and is on a steep grade. The stream was measured at a foot log about 3 miles above its mouth, where it flows through a sandy meadow or bottom one-fourth of a mile wide. So far as examined this stream offers a number of good mill sites, for its valley is everywhere bounded by steep mountain sides, and in many places is narrow, by reason of the occurrence of bands of resistant gneiss and schist.

LOUIS FORK.

This stream has a large drainage basin, served by its two branches, East Fork and West (or South) Fork. The valleys of these branches are generally open and are largely cleared, the bottom lands, of which there is a large area, being under cultivation. The discharge was measured (see table on page 164) at a foot log where the Mount Pleasant road crosses the stream, just below the confluence of the East and West forks. The bottom at this place is rather sandy and gravelly, with some large bowlders. About one-fourth of a mile downstream, however, the creek leaves the meadows and enters a narrow, steep-sided gorge containing many rocky ledges. There are one or two small gristmills on the forks above the point of measurement, which is nearly 3 miles from the mouth, but so far as known there are none below it.

UNNAMED TRIBUTARY EAST OF LOUIS FORK.

There is a small stream which heads in the mountains northeast of Purlear and enters the Yadkin from the north about a mile west of Brown's ford, on which there is considerable fall, over rock ledges, at the mouth. This fall is utilized by a gristmill and yields a head of 10 feet, although the dam is only 5 feet high. The stream is so small that it was not possible to measure its discharge satisfactorily with the large meter. Judging from the wooded character of its valley, however, it has a fairly uniform flow throughout the year, and its steep grade gives much more power than is now used.

REDDIE RIVER.

This river heads far up among spurs of the Blue Ridge, between Horse Gap on the west and Mulberry Gap on the east. Its headwaters are moderately well wooded, but along its middle course there is more open and cleared valley land. There are several mills on the stream, the more important ones being a gristmill at Whittington and two mills at its mouth, just above North Wilkesboro. The latter mill site is an admirable one, the shoal being 10 or 15 rods wide, rock-floored, and excellent rock abutments being furnished by the ledges on either bank. The natural fall in the channel is about 10 feet, half of which is utilized, by means of a 9-foot dam, by a gristmill and flour mill on the west bank. One hundred yards below the dam a sash factory uses a fall of about 14 feet, obtained by sluicing the water from the dam to the east bank of the stream.

The river is reported to be not subject to rapid fluctuation, thus distinguishing it from most of the other streams of the neighborhood.

MULBERRY RIVER.

This river also rises far back in the Blue Ridge, starting near Mulberry Gap and flowing southeastward. Its valley, which is rather broad, is covered with alluvium and offers relatively few mill sites. The average grade of the channel seems to be much less than that of most of the streams of the district. In the upper stretches falls and rapids are more numerous than in the lower portions of its course. About halfway between Mulberry and Halls Mills there is a shoal which affords fall for Wood's gristmill and sawmill, giving the wheel 8 feet head. So far as known this is the only mill on the stream. At the crossing of the road between North Wilkesboro and the town of Roaring River there is an excellent little fall of about 6 feet, due to a broad ledge of rock which crosses the stream and furnishes a good abutment on the west bank. At the Southern Railway trestle there is also a series of cascades furnishing 6 feet fall, with good abutments on the east bank. The river was measured at the trestle, which is about halfway between the Yadkin and the steep hillside forming the northern boundary of that river's flood plain.

ROARING RIVER.

This stream is much larger than Mulberry River and possesses many good water powers. Those at present best known are the one about 4 miles below Dockery, which is near the junction of the eastern and western forks, and the one at the mouth of the stream.

Just above the confluence of the two chief forks a small stream enters the western fork from the southwest. Where the road from Round Mountain to Dockery crosses it the average fall is 100 feet per mile. Here Spencer Blackburn has built a small mill which uses a fall of 20 feet. Passing on to the two forks and to the main stream below the ford of the eastern road from Round Mountain to Dockery, the river is very rapid and is confined between high and steep banks. Its fall averages 20 feet to the mile, and the shoals, including the Big Shoals, cover a distance of about 1 mile. All of this fall can be made to furnish excellent power, both on the main stream and on the northern fork, which joins the river at this point, after draining a region to the northeast lying between Hank Store and Lomax.

Though narrow and steep sided in the vicinity of the Big Shoals, the valley widens a short distance below, and the stream possesses no valuable powers until about one-fourth mile above the railway trestle at its mouth, where a series of cascades over firm rock ledges causes the channel to drop 15 feet within half as many rods. At the trestle the valley opens out into the sandy flood plain of the Yadkin.

BIG ELKIN RIVER.

This stream has three noteworthy falls, which give it an important place among the water powers of the upper Yadkin Valley. The most important falls, or series of falls, so far as water power is concerned, are Carters Falls, about 3 miles above the mouth of the stream, at a place known as Cool Spring Church. When visited during the summer of 1900 these falls had a comparatively small volume of water. They are occasioned by a broad band of resistant hornblende-gneiss. The upper fall, which is the greater, was measured by a hand level and found to be 60 feet in a distance of 100 yards. From the foot of this fall the stream runs over low ledges for an eighth of a mile to a lower fall which is about 15 feet high. The latter fall is utilized by a small turbine-driven gristmill on one bank and by a small lumber mill on the other bank. The owner of the land states that he has measured the total fall here, from the head of the upper to the foot of the lower falls, by means of accurate instruments, and finds it to be 92 feet, which seems quite possible. The banks of the gorge are steep and of firm rock, affording the finest water-power site between Ararat River and the source of the Yadkin.

About a half mile below the lower falls mentioned there is a fall of about 25 feet, part of which has been utilized by Butler's gristmill, which has a dam 6 feet high yielding 14 feet head. By extending the race a few yards farther downstream a head of 20 feet could be obtained. During high water there is a maximum rise of 3 feet above the top of the dam.

The other powers are near the mouth of the river, in the towns of Elkin and Elkin Valley. At the former place, where there is a favorable rock bottom and decided falls, are two dams; at the latter place, which is higher upstream, there is a gristmill and flour mill with a 10-foot dam and a fall of 18 feet.

MITCHELL RIVER.

This stream was measured just below a series of low rapids over rocky ledges, marking the point of transition from the rocky channel of back country to the sandy flood plain of the Yadkin. The fall, about 10 feet, has not been utilized though it is favorably situated. About 1 mile upstream Burch's flour mill obtains power from a tributary—Snow Creek. At Guyer Ford, 6 miles above the mouth, there is a broad shoal which would give 5 to 7 feet fall within a quarter of a mile.

The valley of Mitchell River is similar to that of Fisher River, being rather narrow, with steep side slopes, but it has been somewhat more cleared than the latter valley. Perhaps half the area of the immediate slopes is now bare of trees, while in the valley of Fisher River two-thirds of the timber seems to be standing.

FISHER RIVER.

This stream was ascended only a short distance. No improved mill sites were found, though a number of small mills are reported along its upper course. Many mills, however, are located on small tributaries of the river. The stream is a large one, being 30 to 40 miles long, rising far back upon the Blue Ridge, in about the same latitude as Mount Airy. Probably the only good mill site is at the neck of what is known locally as The Oxbow or The Horseshoe, a semicircular bend in the river about 5 miles southeast of Dobson. The two arms of this loop come within 100 yards of each other at the narrow neck, and there is said to be a difference of 20 feet in the surface level of the river on the two sides. It has been suggested that this difference in level be utilized by piercing the neck with a tunneled race, but nothing in that direction has yet been done. At the ford of the road between Snow's mill and Butcher there are shoals due to a fall of perhaps 5 feet in one-fourth of a mile, and at the ford southwest of Butcher there is a long shoal giving 4 or 5 feet fall in 200 yards. The valley appears too wide for dam construction, but just below the second shoal mentioned it narrows and closes in for a short distance.

ARARAT RIVER.

Ararat River is the largest of the upper tributaries of the Yadkin. It rises on the Blue Ridge, about 10 miles north of Mount Airy, at an elevation of 2,500 feet, and flows almost due south for 30 miles, emptying into the Yadkin 1 mile below Siloam. The average fall per mile from the mouth to Mount Airy, a distance of 20 miles, is 14.6 feet. Above Mount Airy, where the fall is much greater, there are a number of small gristmills.

NEW RIVER.

New River rises in Watauga County, N. C., and flows in a general northeasterly direction through Watauga and Ashe counties. It then follows the North Carolina-Virginia State line for about 12 miles, when it turns to the north and joins Kanawha River, its waters finally reaching the Ohio. Just before it intersects the North Carolina-Virginia boundary line there is a confluence of two branches of almost equal size, known as the South Fork and the North Fork. The North Fork drains the eastern slopes of the Iron Mountains along the southwestern border of Ashe County, N. C. Both forks are formed by the junction of several branches which drain the mountain slopes. The total drainage area of the two forks is 631 square miles.

Examination of the drainage basin of the river was made as far down as Oldtown, in Grayson County, Va., about 7 miles below the confluence of the North and South forks. The upper part of the basin is rough and mountainous, the stream flowing through gorges and narrow valleys with rocky slopes and bottoms. The occasional widening of the valleys, however, furnishes favorable sites for dams and mills. The soil is for the most part deep and fertile, making a fine agricultural region. According to the census of 1880, 92,000 acres were under cultivation, 57,000 acres were in grass, and 240,000 acres, or 61 per cent of the whole, were in original timber. The annual rainfall in the basin, as indicated by a single station, viz, Blowing Rock, is about 49 inches, distributed as follows: Spring, 11.3 inches; summer, 16.2 inches; autumn, 9.7 inches; and winter, 11.8 inches. The region is rich in mineral resources, especially in iron and copper, though very little has been done in the way of development.

The total length of the river between the junction of the forks and Oldtown, Va., is about 35 miles, and the average fall per mile about

8.5 feet. The river winds its way in narrow gorges formed by the shutting in of the hills on either bank. Bottom land is therefore scarce. The section of Virginia through which this portion of the river flows is chiefly devoted to stock raising. The land is fertile and the soil deep and of a reddish color. The region is well settled, the people thrifty, and large and well-cultivated farms can be seen everywhere. Wheat and other grains are the chief crops.

During the investigation a gaging station was established (July 31, 1900) near Oldtown, Va., and two measurements were made there (see table below). Measurements were also made of tributaries of the river between the confluence of the North and South forks and Oldtown, as shown in the following table. The basins of the North and South forks are described under separate headings, and the measurements made on those streams and their tributaries are given in the tables on pages 172 and 174.

Discharge measurements of New River near Oldtown, Va., and of its tributaries between confluence of North and South forks and Oldtown.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge
1900.				*Feet.*	*Sec.-ft.*
July 28	Wilson Creek	2 miles above mouth	Cleveland Abbe, jr., and N. C. Curtis.	6.3	35.1
Oct. 28	do	do	do	6.1	78.0
July 29	Fox Creek	One-fourth mile above mouth.	do		85.0
Oct. 28	do	do	do		144.0
1901.					
June 28	do	do	do		352.0
1900.					
July 31	Peach Bottom Creek	200 yards above mouth.	do	4.9	21.4
Oct. 29	do	do	do		36.0
July 31	Little River	Ford of Independence-Oldtown road.	do	9.1	199.0
Oct. 29	do	do	do		318.2
July 30	Elk Creek	200 yards above mouth.	do	4.0	57.1
July 31	New River	Near Oldtown	do	6.6	1,541.0
Oct. 29	do	do	do	6.3	2,293.0

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

The water powers of all of the streams mentioned in the foregoing table are excellent, and many of them have already been developed. At the mouth of Wilson Creek there are two mills—the lower one a grain mill with a fall of 12 feet, and the upper one a woolen factory, owned by Fields & Hash. On Peach Bottom Creek, 2 miles east of Independence, is the gristmill of D. C. Mallory. The total fall here is about 65 feet.

SOUTH FORK OF NEW RIVER.

GENERAL FEATURES.

This stream is formed by the confluence of the East Fork, the Middle Fork, and Flannery Fork, near Deckhill, Watauga County, N. C. The Middle Fork, which is the largest of the three tributaries mentioned, rises just north of Blowing Rock, at the boundary line between Watauga and Caldwell counties, at an elevation of between 3,700 and 3,800 feet. The elevation at the junction of the North and South forks being 2,500 feet, the difference in elevation between the head and the mouth of the South Fork is 1,300 feet, the distance 45 miles. This gives an average fall of 29 feet to the mile. As the course of the stream, however, is extremely crooked the slope is hardly 20 feet to the mile. Shoals and available water powers are not numerous on the main stream, but on the branch streams they are more frequent and have been more extensively utilized.

The area drained by the South Fork presents a very great diversity of scenic features. The general course of the stream is parallel to the Blue Ridge. On the north are very high knobs and ridges. The highest of these is Snake Mountain, 5,594 feet high. The scenery presented though not rugged is extremely beautiful. The basin of the river is for the most part closed, and there are no extensive bottom lands.

The proportion of unimproved cleared land in Watauga and Ashe counties is small compared with the agricultural lands. On many of the mountains the timber is practically untouched. The trees, however, are not of the most valuable varieties. They are chiefly maples and chestnuts. The larger portions of the cleared land are devoted to the production of grass and hay, and consequently the raising of cattle and sheep is a most important industry. The chief crops are corn, wheat, buckwheat, and cabbages, to all of which the soil is especially well adapted. Large quantities of apples are also produced. The people are well to do and prosperous. The region is very healthful; typhoid and malarial fevers are unknown.

No railroad has yet penetrated Watauga County, though a route has recently been surveyed and a tax voted. The route surveyed crosses the Blue Ridge at Cook Gap. The country roads are for the most part good and are being improved and kept open for travel. The turnpike between Boone and Blowing Rock is remarkably well graded, and it is possible for loaded wagons to cross the Blue Ridge to Lenoir throughout the year. Lenoir is at present the shipping point for the produce of the county. The people of Ashe County are not so progressive in the matter of road building as are the people of Watauga County.

Both the North Fork and the South Fork are at times swollen by heavy freshets, which are often very destructive to crops on the bottom lands. Occasionally the soil is entirely removed from the bottoms and the bed rock exposed. More often, however, where the current is not very swift, a rich coating of black mud from one-half inch to 4 inches thick is deposited, enriching the lowlands considerably.

DISCHARGE MEASUREMENTS IN BASIN.

During the investigation a gaging station was established on the South Fork at New River, N. C. The measurements made there, as well as those made at Riverside, also the measurements made on the tributaries, are given in the following table, in order downstream:

Discharge measurements of South Fork of New River and its tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 28	South Fork of New River	New River	Cleveland Abbe, jr., and N. C. Curtis.	2.70	751.0
Oct. 28	do	do	do	2.60	1,635.0
1901.					
June 27	do	do	do	3.90	1,976.0
1900.					
July 18	do	Riverside	do	11.85	165.0
Oct. 25	do	do	do	11.00	741.1
1901.					
June 24	do	do	do		968.0
Do	do	Ford near mouth of Middle Fork of New River, near Boone.	do	7.10	159.0
Do	West Fork	Near Boone	do	5.40	108.0
1900.					
July 23	Flannery Fork	Ford of Boone-Blowing Rock road.	do	6.35	10.4
Oct. 24	do	do	do	5.35	107.0
July 23	Middle Fork	Ford of Boone-Aho road	do	5.70	24.4
Oct. 24	do	do	do		234.0
July 23	East Fork	do	do	5.70	10.4
Oct. 24	do	do	do	5.10	109.0
July 18	Meat Camp Creek	One-fourth mile below Moretz.	do	9.00	35.3
Oct. 25	do	do	do	8.65	89.0
1901.					
June 24	do	do	do	7.90	164.0
1900.					
July 24	Elk Creek	Elk Crossroads	do	8.00	10.0
July 18	Old Field Creek		do	6.1	19.4
July 24	Gap Creek	One-eighth mile above mouth	do	4.85	23.4
July 19	Beaver Creek	At mouth	do	6.00	22.4
July 27	Mulberry Creek	Near mouth	do	5.1	109.0
Do	Prather Creek	One and one-half miles below Scottville.	do	8.6	25.0

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in gage height represents an increase in the discharge of the stream.

WATER POWERS IN BASIN.

There are a number of undeveloped water powers on the South Fork and its tributaries, the chief of which are the following:

On the Middle Fork, about 5 miles from Blowing Rock, there is a fall of possibly 15 feet in 100 feet, with a good dam site, though the space for building purposes is somewhat cramped. On Meat Camp Creek, at Moretz, there is a mill with a dam about 8 feet high. On Elk Creek, at Elk Crossroads, there is a small sawmill. The discharge of this stream is slight, but a fall of about 20 feet has been obtained. On Beaver Creek, at the town of Beavercreek, is Hamilton's corn and flour mill, with a working head of about 10 feet.

Near the mouth of the South Fork are the remains of an old dam. The site is a good one, a rock ledge running entirely across the stream and high hills shutting in close on both banks. A dam 40 feet in height could easily be constructed here. Near Scottville the river makes an almost closed loop, and it has been proposed to tunnel through the neck of the loop and in that way develop a fall. It is said that the difference in the elevation of the surface of the water on the upper and lower sides of the loop is about 30 feet.

Owing to the steep slopes of the adjacent mountains the river and its tributaries are subject to floods, and dams and buildings for the development of the water powers would have to be built strong and substantial.

NORTH FORK OF NEW RIVER.

GENERAL FEATURES.

The North Fork is formed by the junction of Hoskin Fork and Brush Fork in the extreme southwestern part of Ashe County.

The character of the region through which it flows is more mountainous than the basin of the South Fork; the same general agricultural and forest conditions prevail here as in the latter basin. The stream is not so tortuous as the South Fork, but its side streams are more numerous and the fall greater. Its total length is about 30 miles. The difference in elevation between its head and the junction with the South Fork at Weaversford is 1,800 feet, making the average fall per mile 60 feet.

Its main upper branch, Hoskin Fork, rises on the eastern slope of Snake Mountain, at an elevation of 4,300 feet. It flows between closed hills, and its flood plain is very narrow.

The ratio of cleared to forest-covered land in the watershed is estimated to be about 1 to 5. The region about the headwaters is very thinly settled. The scenery is magnificent, especially near Creston and Solitude. The cleared land is chiefly devoted to cattle grazing.

DISCHARGE MEASUREMENTS IN BASIN.

On July 27, 1900, a gaging station was established on the North Fork at Weaversford, N. C. The measurements made there, as well as those made at other points along the river, also the measurements made on its tributaries, are given in the following table, in order downstream:

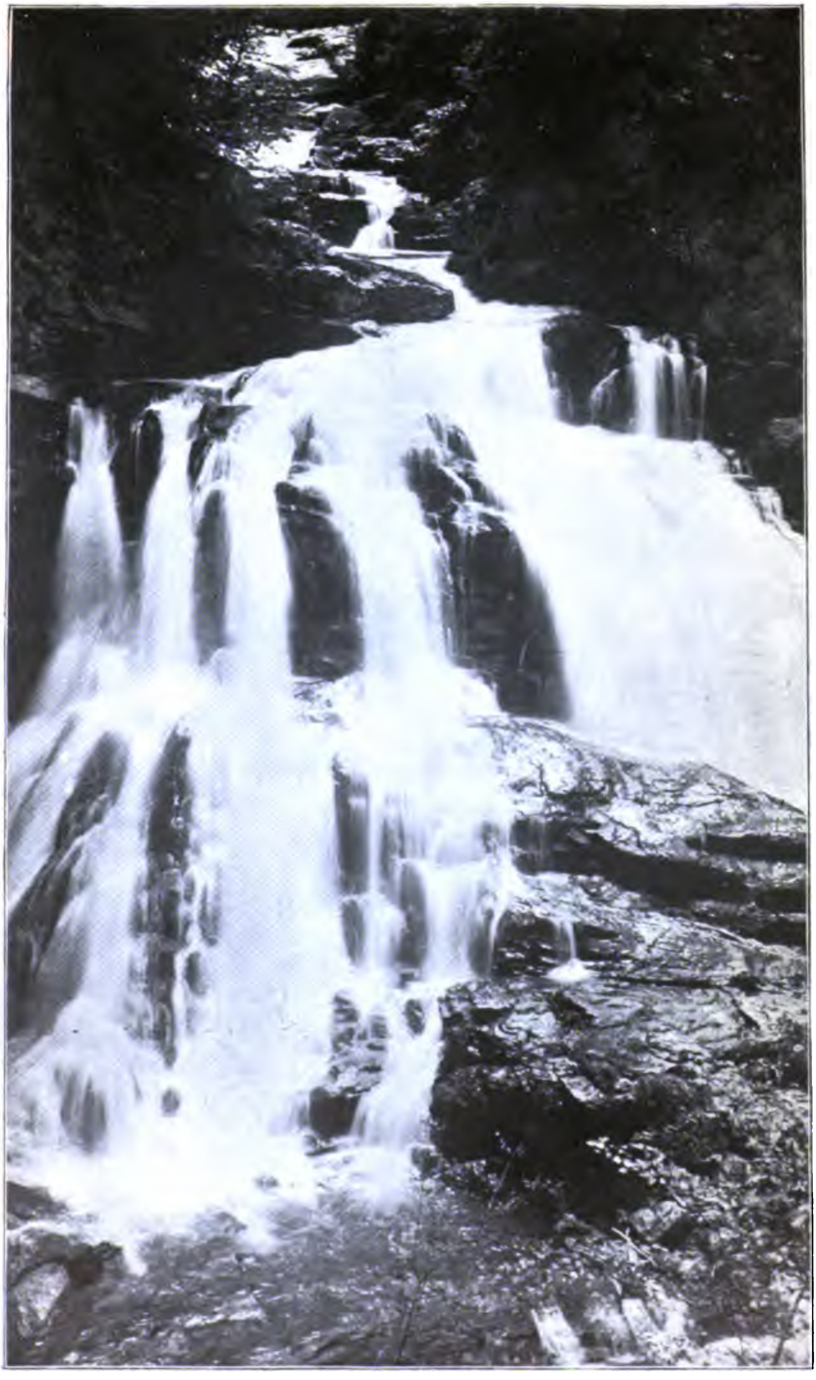
Discharge measurements of North Fork of New River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 28	North Fork of New River.	Weaversford	Cleveland Abbe, jr., and N. C. Curtis.	0.60	536.0
Oct. 27	do	do	do	0.90	708.0
1901.					
June 27	do	do	do	1.40	1,377.0
June 20	do	Below mouth of Laurel Creek	do	1.00	313.0
1900.					
July 21	do	1 mile below Creston	do	6.7	49.3
Oct. 26	do	do	do	6.0	194.0
1901.					
June 20	do	do	do	5.5	196.0
1900.					
July 20	do	½ mile from Creston, on road to Solitude.	do	2.65	32.2
Do	Threetop Creek	Creston	do	6.75	180.0
July 21	do	do	do	7.26	37.0
July 20	Big Laurel Creek	100 yards above mouth	do	6.40	26.2
Oct. 26	do	do	do	6.30	80.4
July 20	Buffalo Creek	½ mile above mouth	do	5.43	44.0
Oct. 26	do	do	do		67.0
1901.					
June 20	do	Near Jefferson	do	4.30	140.0
1900.					
July 25	Horse Creek	¼ mile above mouth	do	6.6	34.3
Oct. 27	do	do	do	6.05	140.0
1901.					
June 25	do	do	do	5.35	444.0
1900.					
July 25	Helton Creek	Below Peasley's mill	do	4.28	30.0
Oct. 27	do	do	do		105.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table made at Weaversford. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS IN BASIN.

There are a number of water powers in the basin. Those of Threetop Creek are very good. Four mills were observed, with falls ranging from 6 to 15 feet. Shoals and dam sites are numerous. At the falls of Long Hope Creek, a branch of Threetop Creek, there is a total fall of 300 feet in 400 yards. The average discharge of Long Hope Creek is about 10 second-feet. On the North Fork about 3 miles west of the mouth of Buffalo Creek, near Dresden, there is an important water power which at one time was utilized, but the dam was destroyed by a freshet and has not been rebuilt. The hillsides at this point shut



LOWER FALLS OF CULLASAGEE CREEK, NORTH CAROLINA, A TRIBUTARY OF LITTLE TENNESSEE RIVER.

OCONALUFTY VALLEY, NORTH CAROLINA.

in close, and a rock ledge extends across the stream. A fall of 30 or 40 feet could readily be obtained. Horse Creek and Helton Creek are both large streams with considerable fall. No water powers were observed on the former. A combined sawmill and gristmill is located about a half mile above the mouth of Helton Creek. The fall obtained is about 10 feet and the power is developed by turbines. This is also the site of the old Helton iron works, where hammered iron was formerly worked, the ore being obtained in the vicinity. On the North Fork about 2 miles from its mouth is Dixon's corn and flour mill. A dam about 8 feet in height has been constructed here. The flume leading to the forebay is a tunnel cut through a projecting shelf of rock, behind which is a mill house. A masonry dam 40 feet high could be constructed and the power greatly increased.

STREAMS SOUTHWEST OF FRENCH BROAD RIVER.

South and west of the region already described is a large, mountainous area with many of the same characteristics. From this territory flow the headwaters of four of the largest rivers in the Southeastern States. First comes the Tennessee River, the basins of several of the largest branches of which, namely, the Holston, the Watauga, the Nolichucky, and the French Broad, have been described in detail in this paper. Farther south are the Oconalufty, the Tuckasegee, the Nantahala, the Hiwassee, the Okoee, and other rivers which enter the Tennessee and after a long and winding course add their waters to the Mississippi. (Typical views of these streams are shown in Pls. XXXIX to XLIV.) The second large river is the Savannah, which receives numerous tributaries and flows in a southeasterly direction into the Atlantic. The third stream is the Apalachicola River, which with its chief tributary, the Chattahoochee, rises close to the headwaters of the Tennessee and after a southerly course between Georgia and Alabama and through Florida enters the Gulf of Mexico at Apalachicola. The fourth large stream is the Mobile, which receives its headwaters from the mountains of Tennessee and northern Georgia, through the Coosa, the Conasauga, and the Etowah, and flowing through the State of Alabama enters the Gulf at Mobile.

Hydrographic studies and numerous measurements of discharge, in charge of Prof. B. M. Hall, have been made by the United States Geological Survey of the headwaters of all of these streams and of their chief tributaries. Most of the streams rise on the steep slopes of the mountain sides, at elevations of from 2,000 to 4,000 feet above sea level, and have large falls throughout their courses. In many places the streams flow through mountain gorges with steep, vertical sides and with very small flood plains.

Only a small proportion of the region is under cultivation, the greater part being still covered with the original forest growth, consisting of oak, hickory, chestnut, poplar, locust, pine, buckeye, linn, ash, maple, sassafras, walnut, and other varieties. The ground is frequently covered with trailing arbutus, maidenhair and other ferns, deep-green mosses, and a great variety of wild flowers and rare medicinal plants. The climate is mild throughout the year, making it a fine resort in winter as well as in summer. Wild animals, such as deer, bears, and wolves, once so numerous, are now nearly extinct, but there are still many wild-cats, catamounts, minks, foxes, opossums, ground hogs, polecats, weasels, wild turkeys, pheasants, squirrels, rabbits, quails, etc. The land now under cultivation is practically all that is available for ordinary farming, the remainder being steep, rocky, and rugged, with only occasional patches of deep, fertile soil. Near the rivers considerable timber has been cut, but the lumbering has not extended far up the mountain sides. Means of transportation are exceedingly meager, the Murphy branch of the Atlanta, Knoxville and Northern Railway being about the only outlet. For this reason the few farming products that are raised can not be transported economically to the populated districts, so that there is little incentive to agricultural pursuits. The greater portion of the grain raised is made into moonshine whisky, and the summer apples are largely used for apple-jack. Wheat, cabbages, Irish potatoes, and the hardier fruits grow well.

The mineral resources are practically untouched and comparatively unknown, but they are evidently important and varied. Gold, corundum, asbestos, marble, talc, kaolin, ocher, iron, and mica are known to exist. The whole region is sparsely inhabited. Water powers are very numerous, though few are developed, and most of these on only a small scale, for gristmills and sawmills. The large undeveloped powers on the lower parts of the streams are well distributed and are very valuable for manufacturing purposes. After the rivers leave the mountain region and flow across the broad, elevated plains, large falls frequently occur, some of which have in recent years been developed and have proved to be most lucrative investments.

The results of the measurements upon the streams in this region are given in the following tables, arranged in chronologic order:[a]

Discharge measurements of tributaries of Tennessee River north of Hiwassee River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Feb. 18	Conasauga Creek	Near Cambria, Tenn	B. M. Hall and assistants.		101
Feb. 19	Tellico River	1¼ miles above mouth	do		316
Do	Little Tennessee River.	¼ mile below mouth of Tellico River.	do	3.10	4,774
Feb. 20	Little River	1 mile above mouth	do		374
Feb. 21	West Fork of Little Pigeon River.	At bridge just above mouth	do		133

[a] In making the measurements recorded in these tables bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in gage height represents an increase in the discharge of the stream.

TUCKASEGEE RIVER NEAR DILLSBORO, N. C.

TUCKASEGEE FALLS, NORTH CAROLINA.

Discharge measurements of tributaries of Tennessee River north of Hiwassee River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Feb. 21	Little Pigeon River	At bridge just above junction with West Fork of Little Pigeon.	B. M. Hall and assistants.		167
Feb. 22	East Fork of Little Pigeon River.	Near mouth	do		[a]30
Do	Cosby Creek	At mouth	do		60
Feb. 23	Big Pigeon River	At bridge above mouth of Cosby Creek.	do		778
Apr. 3	Tellico River	At bridge 1¼ miles above mouth.	do		2,580
Do	Little Tennessee River.	McGhee, Tenn	do		30,536
Apr. 4	Little River	Halfway between Louisville and Knoxville, Tenn., at A., K. and N. Ry. bridge.	do		2,012
Sept. 11	Collins River	McMinnville, Tenn	do	2.60	310
Nov. 4	Little Tennessee River.	McGhee, Tenn	do	2.50	2,675
Do	Tellico River	At bridge 1¼ miles above mouth.	do		180

[a] Estimated.

Discharge measurements of Hiwassee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Jan. 10	Stanley Creek	1 mile above mouth	B. M. Hall and assistants.		49.0
Do	Big Creek	Near mouth	do		86.0
Jan. 11	Noontootly Creek	At foot log ¼ mile from mouth.	do		207.0
Do	Toccoa River	At Van Sant's bridge	do	5.05	2,475.0
Do	Skeenah Creek	1 mile above mouth	do		109.0
Jan. 12	Rock Creek	Near mouth	do		132.0
Do	Cooper Creek	Bridge 1 mile above mouth	do		387.0
Do	Toccoa River	1¼ miles above mouth of Cooper Creek.	do		396.0
Do	Mill Creek	At mouth	do		122.0
Do	Toccoa River	Just above mouth of Mill Creek.	do		43.0
Jan. 14	Suches Creek	Near mouth	do		64.0
Do	Toccoa River	Just below Suches Creek	do		175.0
Do	Coosa Creek	Bridge about 2¼ miles from mouth.	do		75.0
Do	Nottely River	Bridge 1¼ miles from Blairsville, Ga.	do	1.45	450.0
Do	Butternut Creek	Just below bridge at mouth	do		32.0
Jan. 15	Arququah Creek	At Choestoe road	do		40.0
Do	Town Creek	¼ mile from mouth	do		85.0
Do	Stink Creek	1 mile above mouth	do		48.0
Do	Nottely River	At foot log just above mouth of Stink Creek.	do		131.0
Do	Wolf Creek	On south side of Nottely River	do		55.0
Jan. 16	Young Cone Creek	1 mile above mouth	do		94.0
Do	Ivy Log Creek	¼ mile above mouth	do		33.9
Jan. 17	Nottely River	At Thompson's bridge at Ivy Log, Ga.	do	1.20	616.0
Jan. 18	Brasstown Creek	At bridge near mouth	do		149.0
Jan. 21	Hiwassee River	Just above mouth of Hightower Creek.	do		152.0
Do	Bell Creek	At mouth	do		24.0
Do	Hightower Creek	Near mouth	do		116.0
Jan. 22	Hiwassee River	Bridge 1¼ miles below Hiwassee, Ga.	do		306.0
Jan. 24	Hemptown Creek	Just above mouth of Youngstone Creek.	do		159.0
Do	Hothouse Creek	About 2 miles above mouth	do		75.0
Jan. 25	Greasy Creek	Near mouth	do		88.0
Jan. 26	Okoee River	Parksville, Tenn	do		1,602.0
Aug. 19	Toccoa River	1¼ miles south of Gaddistown, Ga.	do		67.4
Aug. 20	Williams Creek	¼ mile south of Gaddistown, Ga.	do		22.8
Do	Nickle Creek	¼ mile south of Gaddistown, Ga.	do		12.8

Discharge measurements of Hiwassee River and tributaries—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Aug. 20	Toccoa River	¼ mile southeast of Gaddistown, Ga.	B. M. Hall and assistants.		147.6
Do	Suches Creek	1 mile northeast of Gaddistown, Ga.	do		144.0
Do	Cooper Creek	Near fork between Gaddistown and Blairsville, Ga.	do		251.5
Do	Mulky Creek	do	do		75.0
Do	Nottely River	1 mile southwest of Blairsville, Ga.	do		955.0
Aug. 21	Christopher Creek	2¼ miles southeast of Blairsville, Ga.	do		39.1
Do	Arququah Creek	3¾ miles southeast of Blairsville, Ga.	do		96.0
Do	Foun Creek	6 miles southeast of Blairsville, Ga.	do		279.0
Do	Stink Creek	Near Choestoe, Ga	do		167.0
Do	Choestoe Creek	5¼ miles southeast of Choestoe, Ga.	do		160.0
Aug. 23	Miller Creek	¼ mile northeast of Blairsville, Ga.	do		87.0
Do	Brasstown Creek	1¼ miles southwest of Young Harris, Ga.	do		139.0
Aug. 26	Long Bullet Creek	3 miles northwest of Hiwassee, Ga.	do		[a]26.0
Do	Hog Creek	1¼ miles northwest of Hiwassee, Ga.	do		42.0
Do	Hiwassee River	1 mile northwest of Hiwassee, Ga.	do		1,039.0
Do	Fodder Creek	3 miles southeast of Hiwassee, Ga.	do		110.7
Do	Hiwassee River	3 miles north of Mountain Scene, Ga.	do		529.8
Do	Cinth Creek	2 miles north of Mountain Scene, Ga.	do		89.0
Aug. 27	Hiwassee River	¾ mile north of Mountain Scene, Ga.	do		92.0
Do	Owl Creek	1 mile north of Mountain Scene, Ga.	do		87.1
Aug. 21	Fightingtown Creek	8 miles from mouth	do		236.0
Aug. 22	Weaver Creek	2 miles from mouth	do		97.0

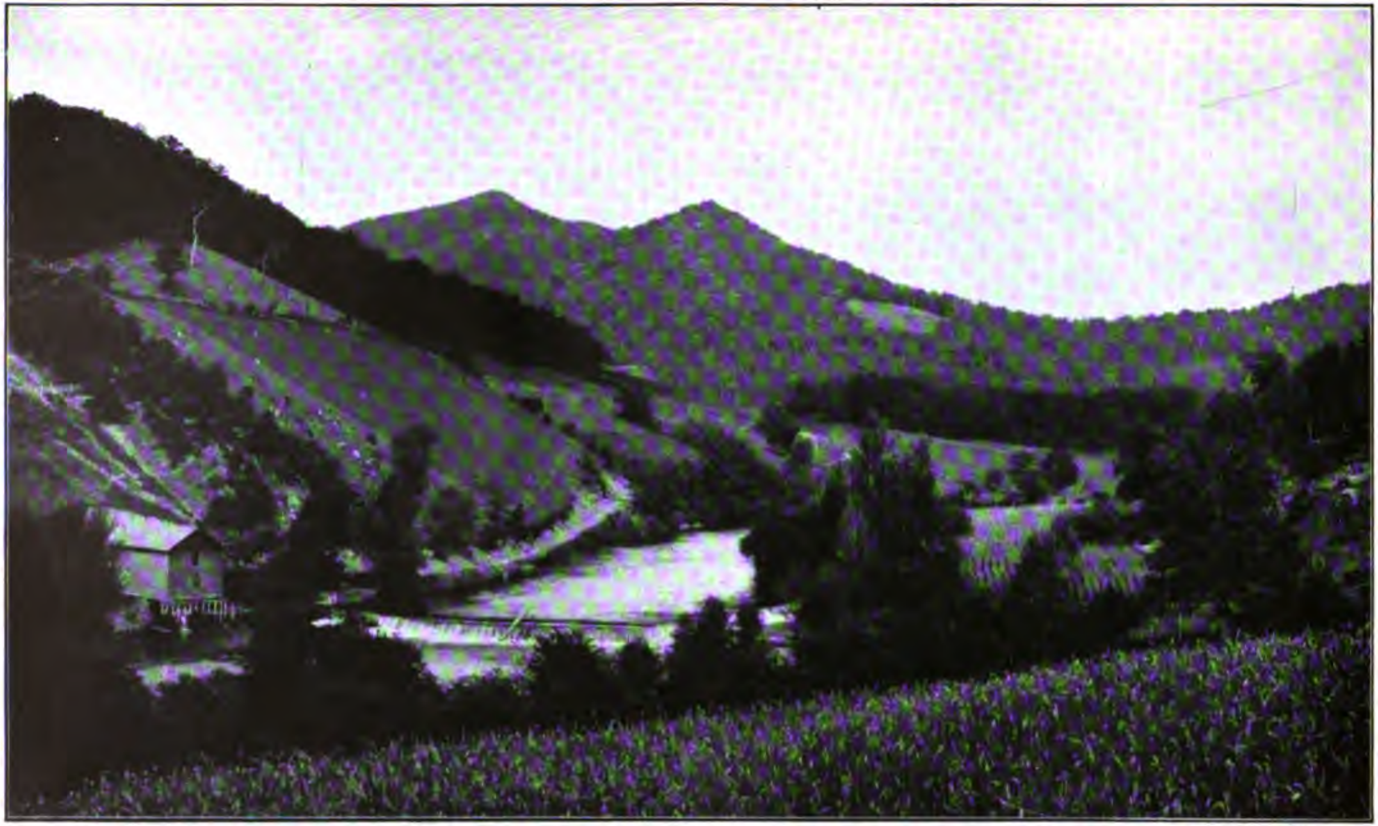
[a] Estimated.

Discharge measurements of Duck and Elk rivers, Tennessee.

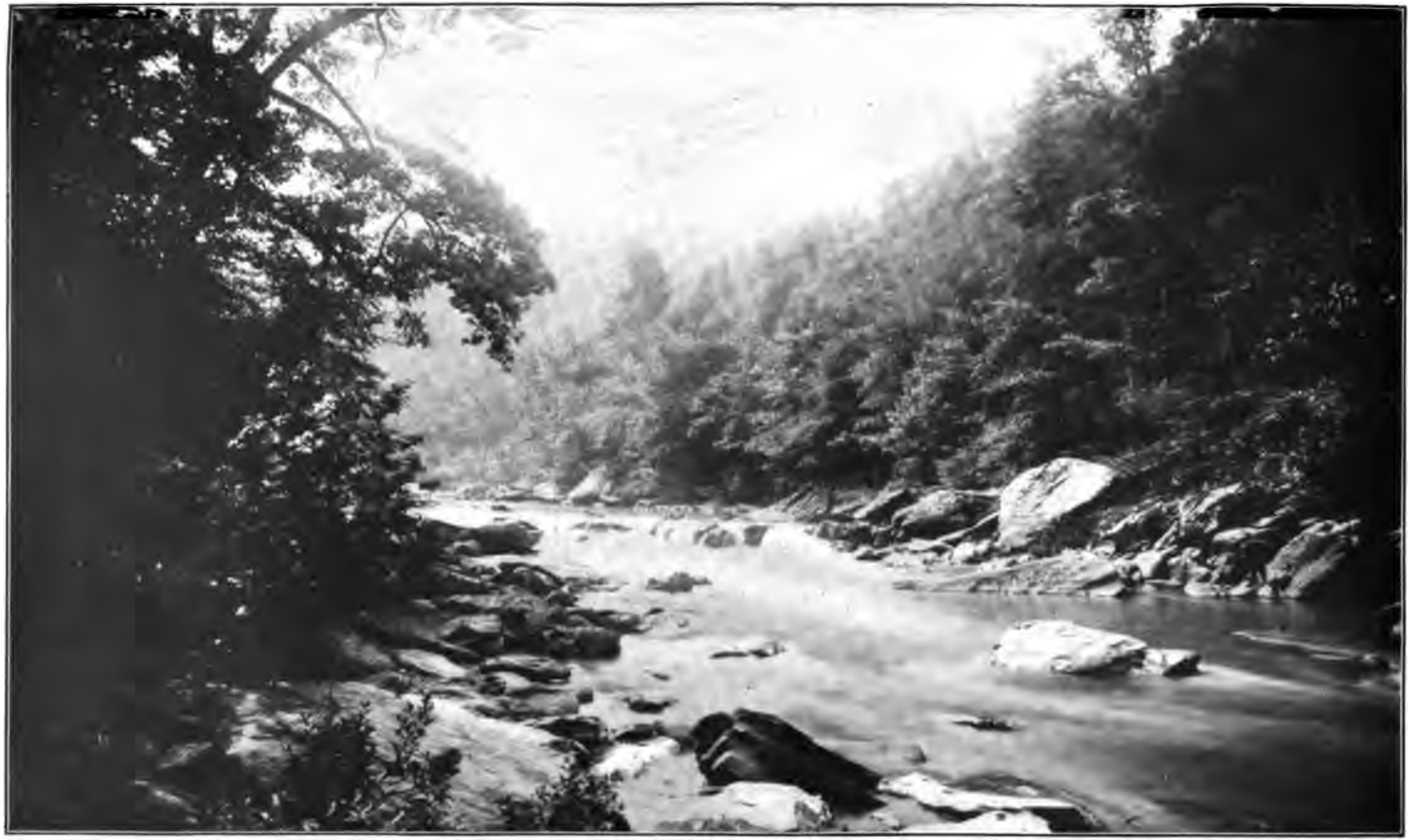
Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Feb. 9	Duck River	Columbia, Tenn	Max Hall	2,418
Do	Elk River	Fayetteville, Tenn	do	1,828
Apr. 19	Duck River	Columbia, Tenn	do	9,504

Discharge measurements of tributaries of Savannah River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Apr. 24	Rocky River	5¼ miles northwest of Calhoun Falls, S. C.	B. M. Hall and assistants.		546.0
Aug. 12	do	do	do		448.0
Aug. 13	Little River	5 miles west of Calhoun Falls, S. C.	do	1.35	107.0
Sept. 30	Stekoa Creek	2 miles south of Clayton, Ga.	do		71.0
Do	Mill Creek	do	do		7.9
Oct. 19	Tiger Creek	Tallulah Falls, Ga., ¼ mile above mouth.	do		151.0



WATER-POWER DEVELOPMENT ON TUCKASEGEE RIVER NEAR PAINTER, N. C.



OKOEE RIVER NEAR DUCKTOWN, TENN.

Discharge measurements of Flint River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Mar. 9	Kinchafoonee Creek	Albany, Ga	B. M. Hall	1,208
Do	Muckalee Creek	1¼ miles above mouth	do	1,777
Do	Blue Spring Creek	4 miles below Albany, Ga	do	95
Mar. 26	Kinchafoonee Creek	Albany, Ga	F. A. Murray	1,920
Do	Muckalee Creek	do	do	3,244
Apr. 17	Flint River	1 mile south of Montezuma, Ga	do	5,099
Apr. 18	Kinchafoonee Creek	Albany, Ga	do	1,741
Do	Muckalee Creek	do	do	2,600
July 18	Flint River	1¼ miles east of Montezuma, Ga	do	2,398
July 19	Kinchafoonee Creek	Near Albany, Ga	do	714
Do	Muckalee Creek	do	do	1,001

Discharge measurements of Chattahoochee River and tributaries in Georgia.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Nancys Creek	7 miles northeast of Atlanta, on Peachtree road.	J. C. Conn	45.9
May 15	Sweetwater Creek	Austell, Ga	K. T. Thomas	188.0
June 25	Chattahoochee River	3¼ miles northwest of Gainesville, Ga.	F. A. Murray	1,306.0
Oct. 24	Baldridge Creek	Near Buford, Ga	Max Hall	23.5

Discharge measurements of Chattahoochee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 12	Yahoola ditch	1 mile east of Dahlonega, Ga	B. M. Hall and assistants.	39.5
Do	Yahoola Creek	2 miles east of Dahlonega, Ga	do	309.2
Do	Chestatee River	5 miles east of Dahlonega, Ga	do	1,477.1
Jan. 13	East Fork of Tessantee Creek.	3 miles northeast of Cleveland, Ga	do	10.3
Do	Dukes Creek	1¼ miles southwest of Nacoochee, Ga	do	285.2
Do	Chattahoochee River	Nacoochee, Ga	do	424.0
Do	Bean Creek	1 mile east of Nacoochee, Ga	do	12.3
Do	Chickamauga Creek	3¼ miles northeast of Nacoochee, Ga	do	109.8
Jan. 14	Soque River	4 miles south of Soque, Ga	do	132.0
Do	Shoal Creek	¼ mile above mouth	do	50.1
Do	Soque River	7 miles south of Soque, Ga	do	202.2
Jan. 15	Hazel Creek	Demorest, Ga	do	94.8
Do	Whites Creek	7 miles west of Demorest, Ga	do	38.2
Do	North Prong of Mossy Creek.	Mossy Creek, Ga	do	51.1
Do	South Prong of Mossy Creek.	do	do	25.0
Do	Flat Creek	Glades, Ga	do	22.5
Jan. 16	East Prong of Little River.	2¼ miles west of Glades, Ga	do	36.4
Do	West Prong of Little River.	4 miles west of Glades, Ga	do	52.4
Do	Wahoo Creek	4 miles east of Price, Ga	do	89.0
Do	Chestatee River	Newbridge, Ga	do	717.2
Aug. 17	Yahoola Creek	Bridge 1 mile northeast of Dahlonega, Ga.	do	241.0
Do	Tate Creek	1 mile southeast of Porter Springs, Ga	do	32.6
Aug. 19	Cane Creek	3¼ miles northwest of Dahlonega, Ga	do	40.5
Aug. 29	Santee Creek	¼ mile east of Santee, Ga	do	316.8
Do	Chattahoochee River	1 mile west of Nacoochee, Ga	do	605.6
Do	East Tessantee Creek	2 miles north of Cleveland, Ga	do	27.8
Aug. 30	Chestatee River	3 miles southeast of Dahlonega, Ga	do	744.1
Aug. 31	Crooked Creek	2¼ miles southwest of Dahlonega, Ga	do	9.0
Do	Chestatee River	Newbridge, Ga	do	1,141.3
Do	Yellow Creek	2 miles southeast of Newbridge, Ga	do	41.0

Discharge measurements of Etowah River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Willieo Creek	¼ mile above mouth	B. M. Hall and assistants.	20.1
Jan. 8	Coopers Sandy Creek	1 mile north of Crabapple, Ga	do	9.0
Do	South Prong of Little River.	2 miles south of Freemansville, Ga	do	21.5
Do	North Fork of Little River.	2 miles north of Freemansville, Ga	do	13.4
Do	Smithwick Creek	¼ mile east of Orange, Ga	do	8.2
Do	Buzzard Flopper Creek.	3 miles east of Orange, Ga	do	6.5
Do	Boardtree Creek	1 mile south of Creighton, Ga	do	7.2
Do	Settingdown Creek	Creighton, Ga	do	74.0
Jan. 9	Etowah River	¼ mile north of Hightower, Ga	do	512.4
Do	Yellow Creek	6 miles northeast of Hightower, Ga	do	32.0
Jan. 10	Amicalola River	Afton, Ga	do	166.4
Do	East Amicalola River.	Weir, Ga	do	58.3
Jan. 11	Nimblewill Creek	1 mile south of Randa, Ga	do	388.3
Do	Etowah River	5¼ miles east of Randa, Ga	do	1,881.0
Jan. 17	Cogburris Creek	1¼ miles above mouth	do	14.6
Do	Etowah River	Hightower, Ga	do	676.1
Jan. 18	Settingdown Creek	¼ mile above mouth	do	178.3
Do	Boardtree Creek	1 mile south of Creighton, Ga	do	9.8
Jan. 19	Willieo Creek	¼ mile above mouth	do	31.0
Aug. 31	Etowah River	1 mile west of Auraria, Ga	do	173.0

Discharge measurements of Cahaba River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 28	Hawkins Spring	¼ mile from Hawkins Station	K. T. Thomas	15.8
Jan. 29	Cahaba River	Sydenton, Ala	do	549.0
Mar. 28	Valley Creek	Adjers Station, Ala	J. R. Hall	378.0
Do	Blocton Creek	Blocton, Ala	do	107.0
Mar. 29	Cahaba River	¼ mile south of Sydenton Station, Ala	do	1,117.0
Do	Buck Creek	¼ mile above mouth	do	179.0
Apr. 25	Cahaba River	2 miles east of Harrell, Ala	do	6,560.0

Discharge measurements of Tombigbee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Feb. 16	Tombigbee River	Waverly, Miss	K. T. Thomas	6,726
Feb. 18	Luxapelila Creek	Columbus, Miss	do	957
Mar. 7	Yalabusha River	Grenada, Miss	do	1,386
Mar. 11	Luxapelila Creek	Columbus, Miss	do	2,459
Apr. 15	Big Black River	1 mile east of Goodman, Miss	do	614
Apr. 16	Luxapelila Creek	Columbus, Miss	do	873
June 26	do	do	do	109
Oct. 31	do	do	do	126

Discharge measurements of tributaries of Mississippi River.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Feb. 14	Sunflower River	Baird, Miss	K. T. Thomas	3,761
Feb. 15	Sakatouchee River	Mhoon Valley, Miss	do	559

Discharge measurements of Tallapoosa River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Tallapoosa River	2 miles from Tallapoosa, Ga	Max Hall	329
Feb. 11	Wind Creek	About 4 miles above mouth	J. R. Hall	66
Do	Saugahatchee Creek	Thaddeus, Ala	do	453
Feb. 13	Blue Creek	½ mile from Susanna, Ala	do	117
Do	Chenehatchee Creek	3 miles above mouth	do	80
Feb. 27	Kowaliga Creek	Kowaliga, Ala	do	154
Mar. 5	Emuckfaw Creek	Near Zana P. O., Ala	do	113
Mar. 11	Moores Creek	1½ miles north of Dudleyville, Ala	do	29
Mar. 12	Chattahaspa Creek	1 mile south of Patillos crossroads, Chambers County, Ala.	do	203
Do	Cohoasoncsa Creek	2½ miles below and west of Milltown, Ala.	do	122
Do	Highpine Creek	½ mile south of Chambers and Randolph County line.	do	89
Do	Beaverdam Creek	1 mile north of Lovina, Ala	do	30
Mar. 13	Cornhouse Creek	Near Level Roads, Ala	do	31
Do	Wildcat Creek	Near Gay P. O., Ala	do	32
Do	Tallapoosa River	About 3 miles below confluence of Big and Little Tallapoosa rivers, at Blakes Ferry.	do	2,400
Do	Crooked Creek		do	183
Do	Hurricane Creek	1 mile north of Almond, Ala	do	29
Oct. 21	Tallapoosa River	Near Tallapoosa, Ga	Max Hall	119
Do	do	do	do	96

Discharge measurements of tributaries of Coosa River in Alabama.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Apr. 5	Choccolocco Creek	1½ miles north of Jenifer, Ala	J. R. Hall	1,170.0
Oct 16	Big Wills Creek	2 miles north of Attalla, Ala	F. A. Murray	107.3
Do	do	do	do	106.8

Discharge measurements of tributaries of Oostanaula River.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Mountaintown Creek.	3½ miles from Ellijay, Ga	B. M. Hall and assistants.	162.0
Do	Ellijay River	Ellijay, Ga	do	165.0
Jan. 8	Cartecay River	do	do	250.0
Do	do	Cartecay, Ga	do	207.0
Do	Anderson Creek	1 mile above mouth	do	37.0
Jan. 9	Tickanetley River	1 mile above mouth of Anderson Creek	do	43.5
Jan. 28	Jacks River	Near its junction with Conasauga River.	do	186.0
Do	Conasauga River	1 mile above mouth of Jacks River	do	119.0
Do	Sheets Creek	Just above mouth	do	12.0
Jan. 29	Sumach Creek	At junction of North and South prongs.	do	58.3
Do	North Prong of Sumach Creek.	Near junction of North and South prongs.	do	19.8
Do	South Prong of Sumach Creek.	do	do	38.5
Do	Mill Creek	Near Dunn, Ga	do	41.8
Do	Holly Creek	Near Fast Mountain, Ga	do	107.0
Do	Rock Creek	Ramsay, Ga	do	41.0
Aug. 19	Talking Rock Creek	Talking Rock, Ga	do	215.0
Do	Talona Creek	½ mile above mouth	do	714.0

INDEX TO PAPERS NOS. 62 AND 63.

A.

Page.
Abbe, Cleveland, jr., acknowledgments to 11
Agriculture, extent and character of 39, 41
Amicalola River, measurement of 180
Anderson Creek, measurement of 181
Ararat River, features of 169
  measurements of 164
Arququah Creek, measurements of 177, 178
Atcheson Creek, measurements of 62
Avery Creek, measurement of 128

B.

Bald Creek, measurements of 109
Bald Mountain Creek, measurements of 109
Baldridge Creek, measurement of 179
Balds, occurrence and character of 20-21
Balsam, occurrence and character of 26
Balsam fir (wind-dwarfed), view showing 26
Balsam Mountains, features of 13
  highest peaks in 14
Bark industry, extent and injury of 26
Bean Creek, measurement of 179
Bell Creek, measurement of 177
Bear Creek (Middle Fork Holston), features of 77
  measurements of 73
Bear Creek (Nolichucky), measurements of 108
Bear Creek (North Toe), water powers of 113
Beaver Creek (New), measurement of 172
  water power on 173
Beaver Creek (Nolichucky), measurements of 108
Beaver Creek (North Toe), water powers of 113
Beaverdam Creek (French Broad), features of 135
  measurements of 128
Beaverdam Creek (Laurel Fork Holston), features of 65-66
Beaverdam Creek (South Fork Holston), measurements of 62
Beaverdam Creek (Tallapoosa), measurement of 181
Beaverdam Creek (Watauga), features of 92-93
  measurements of 86
Beech Creek, features of 92
  measurements of 86
Beidelmans Creek. *See* Sinking Creek (Holston).
Big Creek (French Broad), features of 129
Big Creek (Hiwassee), measurement of 177
Big Creek (Nolichucky), measurements of 109

Page.
Big Black River, measurement of 180
Big Bugaboo Creek, measurement of 164
Big Dry Run, measurement of 86
Big Elkin River, features of 167-168
  measurements of 164
Big Ivy River, measurements of 128
Big Laurel Creek (French Broad), features of 130-131
  measurements of 128
Big Laurel Creek (New), measurements of 174
Big Pine Creek, features of 131
  measurements of 128
Big Pigeon River, measurement of 177
Big Rock Creek (Nolichucky), measurements of 108
Big Rock Creek (North Toe), features of 113-114
Big Wills Creek, measurements of 181
Black Mountains, features of 13
  highest peaks in 15
  lumbering in 28
  name of, derivation of 21
  view in 30
Blevins Creek, measurement of 86
Blocton Creek, measurement of 180
Blowing Rock, N. C., escarpment of Blue Ridge at, view showing 16
Blue Creek, measurement of 181
Blue Ridge, escarpment of, view of 16
  features of 12-13, 17
  rivers rising in 17
Blue Spring Creek, measurement of 179
Boardtree Creek, measurements of 180
Boone Fork of Watauga River, features of 94-95
  measurements of 86
Bowlems Creek, measurements of 109
Boylston Creek, measurement of 128
Branch, L. V., acknowledgments to 11
Brasstown Creek, measurements of 177, 178
Broad River, drainage basin of 139-140
  features of 19
  forests in basin of 140
  measurements of 141
  minerals in basin of 140
  rainfall in basin of 140
  tributaries of, features of 143-146
  tributaries of, measurements of 143
  water powers of 142
Brown Creek, measurements of 109
Brush Creek (Nolichucky), measurements of 108
Brush Creek (Watauga), features of 87
  measurements of 85

Page.
Brushy Fork of Cone Creek (Watauga), measurement of 86
Buck Creek (Cahaba), measurement of 180
Buck Creek (Catawba), features of 152-153
  measurements of 151
Buffalo Creek (Broad), measurement of 143
Buffalo Creek (New), measurements of 174
Buffalo Creek (Watauga), features of 87-88
  measurements of 85
Buncombe County, N. C., features of 118-120
Butternut Creek, measurement of 177
Buzzard Flopper Creek, measurement of 180
Byars Creek, features of 75-76
  measurements of 73

C.

Cahaba River, measurements of 180
  tributaries of, measurements of 180
Cane Branch (Nolichucky), measurements of 109
Cane Creek (Broad), measurement of 143
Cane Creek (Catawba), features of 155
  measurements of 151
Cane Creek (Chattahoochee), measurement of 179
Cane Creek (Nolichucky), measurements of 108
  view of 105
Cane Creek (North Toe), features of 113
Caney Creek, measurement of 128
Caney River, features of 114-115
  measurements of 109
Carlocks Creek, features of 75
Cartecay River, measurements of 181
Catawba River, drainage basin of 147-148
  falls on, view of 146
  features of 19
  floods in, view showing effects of 148
  flow of, minimum 150
  forests in basin of 148
  hillside wash in valley of, view showing 148
  measurements of 148-149
  rainfall in basin of 148
  tributaries of, features of 152-158
  tributaries of, measurements of 151-152
  water powers of 150-151
Catawba River, North Fork, features of 153
  measurements of 151
Cathey Creek (Broad), measurement of 143
Cathey Creek (French Broad), measurement of 128
Cattail Branch, measurements of 109
Cedar Creek, features of 74
  measurement of 73
Center Creek, features of 152
Chattahaspa Creek, measurement of 181
Chattahoochee River, measurements of 179
  tributaries of, measurements of 179
Cheever Improvement Company, forests owned by 29
Chenehatchee Creek, measurement of 181
Chestatee River, measurements of 179
Chestnut, occurrence of 27
Chickamauga Creek, measurement of 179
Chilhowie Creek, features of 75
Choccolocco Creek, measurement of 181
Choestoe Creek, measurement of 178
Christopher Creek, measurement of 178
Cinth Creek, measurement of 178
Clay deposits, views showing 34
Clear Creek, features of 152
  measurements of 151
Climate, features of 22-23
Clingman, General, quoted 31
Cloudland, N. C., features of 113-114
Cocke County, Tenn., features of 121-123
Cogburris Creek, measurement of 180
Cohoasoncsa Creek, measurement of 181
Colbert Creek, measurements of 109
Collins River, measurement of 177
Conasauga Creek, measurement of 176
Conasauga River, measurement of 181
Conn, J. C., acknowledgments to 11
Cooper Creek, measurements of 177, 178
Coopers Sandy Creek, measurement of 180
Coosa Creek, measurement of 177
Coosa River, tributaries of, measurements of 181
Cornhouse Creek, measurement of 181
Cosby Creek, measurement of 177
Cove Creek (Broad), measurements of 143
Cove Creek (Watauga), features of 93-94
  measurements of 86
Cowee Mountains, features of 13
Crabtree Creek (Nolichucky), measurements of 108
Crabtree Creek (North Toe), water powers of 113
Craggy Range, highest peaks in 15
Cranberry Creek, measurement of 86
Crib Creek, features of 152
  measurements of 151
Crooked Creek (Chattahoochee), measurement of 179
Crooked Creek (Tallapoosa), measurement of 181
Cullasagee Creek, N. C., falls of, view of 174
Curtis, N. C., acknowledgments to 11
Curtis Creek, measurements of 151

D.

Dam, splash, view of 108
Dark Ridge Creek, measurement of 86
Davidson River, measurements of 128
Deforestation, effects of 29-30, 31-33, 58, 74
  effects of, views showing 32, 34, 148
Denton Valley Creek, features of 61
  measurements of 53
Doe Creek, features of 90
  measurements of 86
Doe River, features of 88-89
  measurements of 85-86
Doe River Valley, view of 88
Drainage basins, map showing 14
Dry Creek, features of 55
Duck River, measurements of 178
Dukes Creek, measurement of 179
Dutch Creek, features of 94
  measurements of 86

E.

East Amicalola River, measurement of 180
East Branch or Fork of any stream, see the stream.

Page.

- Elk Creek (New), measurements of 170, 172
  - water power on 173
- Elk Creek (Watauga), features of 91-92
  - measurements of 86
  - view of 90
- Elk Creek (Watauga), North Fork, measurements of 86
- Elk Creek (Watauga), South Fork, measurements of 86
- Elk Creek (Yadkin), features of 165
  - measurements of 164
- Elk Falls, N. C., view of 90
- Elk Fork Creek, measurements of 109
- Elk River, measurement of 178
- Elk Shoal Creek, measurement of 109
- Ellijay River, measurement of 181
- Empire Company, forests of and lumbering by 27
- Emuckfaw Creek, measurement of 181
- Enoree River, measurement of 143
- Erosion, extent of 29, 31-32
  - effects of, views showing 32, 34, 148
- Etowah River, measurements of 180
  - tributaries of, measurements of 180

F.

- Fall Creek, measurement of 138
- Fifteenmile Creek, features of 62
  - measurements of 53
- Fightingtown Creek, measurement of 178
- Fires, destruction by 29-30
- First Broad River, features of 143-144
  - measurements of 143
- Fishdam Creek, features of 58
  - measurements of 53
- Fisher River, features of 168-169
  - measurements of 164
- Fish Spring, Tenn., features of 82
- Flannery Fork, measurements of 172
- Flat Creek (Chattahoochee), measurement of 179
- Flat Creek (French Broad), features of 134-135
  - measurements of 128
- Flint River, measurements of 179
  - tributaries of, measurements of 179
- Floods, destruction by 32-33
  - effects of 32-33
  - effects of, view showing 34, 106, 148
- Fodder Creek, measurement of 178
- Fogey Creek, measurements of 86
- Forests, destruction of 26-27, 28-29
  - extent and character of 20, 21, 25-30, 82-83
  - fires in 29-30
  - value of 31-32
  - views showing 20, 26
- Forge Creek, measurement of 86
- Foun Creek, measurement of 178
- Fox Creek, measurements of 170
- French Broad River, drainage basin of 115-123
  - features of 18-19
  - measurements of 124
  - rainfall in basin of 123
  - streams southwest of, features of 175-176
  - transportation facilities in basin of 124
  - tributaries of, features of 129-135
  - tributaries of, measurements of 127-128

Page.

- French Broad River, views of 120, 124
  - water powers of 125-127
- French Broad River, East Fork, measurement of 128
- French Broad River, Middle Fork, measurement of 128
- French Broad River, North Fork, measurements of 127
- French Broad River, South Fork, measurement of 128
- French Broad River, West Fork, measurements of 128

G.

- Gaging stations, location of 35
  - map showing location of 14
- Gap Creek (New), measurement of 172
- Gap Creek (Watauga), features of 88
  - measurements of 85
- Geology, features of 15-17
- Gneiss (decomposed), erosion in, view showing 32
- Grandfather Mountain, elevation of 153
  - features of 21-22, 81-82
  - forests of 21, 26
  - views of 22, 26, 38
- Grandmother Mountain, elevation of 153
- Grassy Creek, measurements of 108
- Graves, E., acknowledgments to 11
- Greasy Creek, measurement of 177
- Green River, features of 145-146
  - measurements of 143
- Grose Creek, features of 68
  - measurements of 63

H.

- Hall, B. M., acknowledgments to 11, 175
- Hall, J. R., acknowledgments to 11
- Hall, M., acknowledgments to 11
- Hall, W. E., acknowledgments to 11
- Halls Creek, features of 75
  - measurement of 73
- Hard woods, occurrence and character of 26, 28
- Hatcher Creek, features of 55
  - measurement of 53
- Hawkins Spring, measurement of 180
- Hayes Creek, features of 132
- Hazel Creek, measurement of 179
- Helton Creek, features of 175
  - measurements of 174
- Hemptown Creek, measurement of 177
- Henderson County, N. C., features of 117-118
- Hensons Creek (Nolichucky), measurement of 109
- Hensons Creek (North Toe), low-water flow of 113
  - water powers of 113
- Hickory Nut Creek, measurement of 143
  - view of 140
- Hickory Nut Gap, N. C., view of 140
- Highpine Creek, measurement of 181
- Hightower Creek, measurement of 177
- Highways. *See* Roads.
- Hillside slopes, agriculture on 29, 30
- Hillside wash. *See* Erosion.

Page.

- Hiwassee River, measurements of 177, 178
  - tributaries of, measurements of 177-178
- Hog Creek, measurement of 178
- Hogthief Creek, features of 74
  - measurements of 73
- Hogtrough Creek, features of 68-69
  - measurements of 63
- Hollins Creek, measurement of 143
- Hollow Poplar Creek, features of 110
  - measurements of 108
- Holly Creek, measurement of 181
- Holmes, J. A., acknowledgments to 9, 11
- Holston River, agriculture in basin of 41
  - drainage basin of 36-40
  - features of 18
  - lumber in basin of 41
  - minerals in basin of 41
  - rainfall in basin of 40
  - transportation facilities in basin of 41-42
- Holston River, Middle Fork, drainage basin of 69-70
  - measurements of 70
  - tributaries of, features of 74-77
  - tributaries of, measurements of 73
  - water powers of 70-73
- Holston River, South Fork, drainage basin of 42-46
  - fall or slope of 42
  - forests in basin of 47
  - measurements of 48
  - minerals in basin of 47
  - rainfall in basin of 47
  - transportation facilities in basin of 47
  - tributaries of, features of 53-69
  - tributaries of, measurements of 53, 62-63
  - water powers of 48-53
- Hominy Creek, measurements of 128
- Horse Creek (New), measurements of 174
- Horse Creek (Nolichucky), measurements of 109
- Hothouse Creek, measurement of 177
- Hot Springs, N. C., features of 121
- Hungry Mother Creek, features of 76
  - measurements of 73
- Huntsdale, Tenn., development of 28
- Hurricane Creek, measurement of 181
- Huttons Branch, features of 75
  - measurements of 73

I.

- Indian Creek, features of 54
- Ivy Log Creek, measurement of 177
- Ivy River, features of 132-133

J.

- Jack Creek, measurements of 108
- Jacks River, measurement of 181
- Jacobs Creek, features of 60
  - measurements of 53
- Jarrett Creek, measurement of 151
- Jim Scot Branch, measurements of 63
- Jonah Creek, features of 58
  - measurements of 53
- John River, features of 157-158
  - measurements of 152
- Johnson County Cove, features of 38

K. Page.

- Keith, A., quoted on geology of region 15-17
  - quoted on soils and deforestation 31-32
- Kentucky Fork of North Toe River, measurement of 109
- Kinchafoonee Creek, measurements of 179
- King Creek, measurement of 128
- Kowaliga Creek, measurement of 181

L.

- Laurel Branch, features of 129
- Laurel Creek, features of 93, 94
- Laurel Creek, lower. *See* Lower Laurel Creek.
- Laurel Creek, upper. *See* Upper Laurel Creek.
- Laurel Fork of Doe River, features of 89
  - measurements of 85
- Laurel Fork of Holston River, features of 63-67
  - measurements of 62
- Lees Creek, measurements of 128
- Lime, manufacture of 43, 46
- Linville Gap, elevation of 153
- Linville Improvement Company, lands owned by 21-22
- Linville River, falls of, view of 154
  - features of 153-155
  - measurements of 151
- Little River (Chattahoochee), East Prong, measurement of 179
- Little River (Chattahoochee), West Prong, measurement of 179
- Little River (Etowah), North Prong, measurement 180
- Little River (Etowah), South Prong, measurement of 180
- Little River (French Broad), measurements of 128
- Little River (New), measurements of 170
- Little River (Savannah), measurement of 178
- Little River (Tennessee), measurements of 176, 177
- Little Bald Mountain Creek, measurements of 109
- Little Crabtree Creek (Nolichucky), measurements of 109
- Little Crabtree Creek (South Toe), features of 114
- Little Doe River, features of 88-89
  - measurements of 85
- Little Elk Creek, measurement of 86
- Little Pigeon River, measurement of 177
- Little Pigeon River, East Fork, measurement of 177
- Little Pigeon River, West Fork, measurement of 176
- Little Pine Creek, features of 132
  - measurements of 128
- Little Tennessee River, measurements of 176, 177
- Locust Creek, measurements of 109
- Long Creek, features of 129
- Long Bullet Creek, measurement of 178
- Louis Fork of Yadkin River, features of 165-166
  - measurements of 164
- Lower Creek, features of 158
  - measurements of 152

Page.
Lower Laurel Creek, measurements of 86
Lumbering, extent and methods of 25-29
Luxapelila Creek, measurements of 180

M.

Madison County, N. C., features of 120-121
Maple Creek, measurement of 143
Map, drainage basin and gaging stations 14
  mountain ranges and drainage 11
Martin Creek, measurements of 108
Meat Camp Creek, measurements of 172
  water power on 173
Middle Creek, measurements of 109
Middle Fork or Branch of any stream, *see* the stream.
Middle Saludà River, features of 137
  measurements of 138
Mill Creek (Catawba), measurements of 151
Mill Creek (Hiwassee), measurement of 177
Mill Creek (Oostanaula), measurement of 181
Mill Creek (Savannah), measurement of 178
Mill Creek (South Fork Holston) features of 68
  measurements of 63
Mill Creek (Watauga), features of 90-91
  measurement of 86
Miller Creek, measurement of 178
Mills River, measurements of 128
Mineral resources, character and extent of 33
Mitchell, Professor, quoted 21
Mitchell River, features of 168
  measurements of 164
Moody Mill Creek, measurement of 86
Mooneyham Branch, features of 120
Moores Creek, measurement of 181
Morganton Improvement Company, forests owned by 29
Morrills Creek, features of 55-56
Mossy Creek, North Prong, measurement of 179
Mossy Creek, South Prong, measurement of 179
Mountain Creek, measurements of 143
Mountaineers, homes of 30
  homes of, views showing 30
Mountains, elevations of 12
  geology of 15-17
  physiography of 11-15
Mountain Island Shoal, North Carolina, view of 124
Mountaintown Creek, measurement of 181
Mount Mitchell, features of 21
Muckalee Creek, measurements of 179
Mud Creek, measurement of 128
Muddy Creek, measurements of 151
Mulberry Creek (Catawba), measurements of 152
Mulberry Creek (New), measurement of 172
Mulberry River, features of 166-167
  measurements of 164
Mulky Creek, measurement of 178
Myers, E. W., acknowledgments to 11

N. Page.

Nantahala Mountains, mean elevation of 13
Nancys Creek, measurement of 179
New River, features of 169-170
  measurements of 170
  tributaries of, features of 170-175
  tributaries of, measurements of 170
New River, East Fork, measurements of 172
New River, Middle Fork, measurements of 172
  water power on 173
New River, North Fork, features of 173
  measurements of 174
  tributaries of, measurements of 174
  water powers in basin of 174
New River, South Fork, features of 171-172
  measurements of 172
  tributaries of, measurements of 172
  water powers in basin of 173
New River, West Fork, measurement of 172
Newell, F. H., letter of transmittal by 9
Newfound Creek, features of 135
  measurements of 128
Nickle Creek, measurement of 177
Nimblewill Creek, measurement of 180
Nolichucky River, drainage basin of 105-106
  features of 18
  forests in basin of 106
  measurements of 107
  minerals in basin of 106-107
  rainfall in basin of 106
  water powers of 107
  tributaries of, features of 110-115
  tributaries of, measurements of 108-109
  views of 106
Nooutootly Creek, measurement of 177
North Branch or Fork of any stream, *see* the stream.
North Indian Creek, features of 110
  measurements of 108
North Saluda River, features of 136-137
  measurements of 138
North Toe River, features of 111-112
  measurements of 108
  tributaries of, features of 112-114
Nottely River, measurements of 177, 178

O.

Oconalufty Valley, view of 174
Okoee River, measurement of 177
  view of 178
Old Field Creek, measurement of 172
Oostanaula River, tributaries of, measurements of 181
Owl Creek, measurement of 178

P.

Pacolet River, measurement of 143
Paddy Creek, features of 153
  measurements of 151
Pawpaw Creek, measurement of 128
Peach Bottom Creek, measurements of 170
Pedee River. *See* Yadkin River.
Physiography, features of 11-15
Pigeon Creek, measurements of 108
Pigeon Roost Creek (Nolichucky), measurements of 108

Page.
Pigeon Roost Creek (North Toe), features of ... 113
Pinchot, Gifford, reference to ... 25
Pine, forest of, view showing ... 26
Plant growth, character and extent of ... 31
density of, view showing ... 30
Plumtree Creek (Nolichucky), measurement of ... 109
Plumtree Creek (North Toe), water powers of ... 113
Pomer Creek, features of ... 69
measurements of ... 63
Poplar, forest of, view showing ... 26
occurrence of ... 27
Powdermill Creek, features of ... 113
Prather Creek, measurement of ... 172
Precipitation, extent and character of ... 23-25
Price Creek, measurements of ... 109
Pulp mills, wood cut for ... 28
Puzzle Creek, measurement of ... 143

R.

Railroads, names and location of ... 20, 25, 27, 28, 29, 47, 58, 83
See also Transportation.
Rainfall. *See* Precipitation.
Reddie River, features of ... 166
measurements of ... 164
Reedy Patch Creek, measurement of ... 143
Reems Creek, features of ... 135
measurements of ... 128
Rhododendrons, occurrence and character of ... 26
thicket of, view showing ... 26
Richland Valley, view of ... 20
Riddle Creek, features of ... 58
measurements of ... 53
Ritter Company, forests of and lumbering by ... 27-28
Rivers, general features of ... 17-20
Roads, character of ... 20, 33-34
views of ... 34, 36, 38
Roan Creek, features of ... 89-91
measurements of ... 86
Roan Mountain, features of ... 21
Roaring Creek (Nolichucky), measurement of ... 109
Roaring Creek (North Toe), features of ... 113
Roaring River, features of ... 167
measurements of ... 164
Robersons Creek, measurement of ... 143
Rock Creek (French Broad), features of ... 129
Rock Creek (Hiwassee), measurement of ... 177
Rock Creek (Nolichucky), measurements of ... 108, 109
Rock Creek (Oostanaula), measurement of ... 181
Rock disintegration, extent of ... 31-32
Rockhouse Creek, measurements of ... 86
Rocky bed of mountain streams, view showing ... 105
Rocky River, measurements of ... 178
Rosenbaums Creek, features of ... 67
Rush Creek, features of ... 67
measurements of ... 63
Run-off, effect of sinks on ... 39-40, 43

S. Page.

St. Clair Creek, features of ... 68
measurements of ... 63
Sakatouchee River, measurement of ... 180
Saluda River, features of ... 19-20, 135-138
measurements of ... 138
tributaries of, measurements of ... 138
Sand deposits, views showing ... 34
Sandymush Creek, features of ... 134
measurements of ... 128
Santee Creek, measurement of ... 179
Sapphire country, N. C., topography in, view showing ... 24
Saugahatchee Creek, measurement of ... 181
Savannah River, tributaries of, measurements of ... 178
Sawmill and gristmill, combined, view of ... 108
Scadin, R. H., acknowledgments to ... 11
Scenery, features of ... 20-22
Second Broad River, features of ... 144-145
measurements of ... 143
Settingdown Creek, measurements of ... 180
Shady Valley, features of ... 38, 65-66
Sharp Creek, features of ... 58-59
measurements of ... 53
Sheets Creek, measurement of ... 181
Shell Creek, measurement of ... 85
Shelton Laurel Creek, features of ... 131
Shoal Creek, measurement of ... 179
Shutin Creek, features of ... 130
measurement of ... 128
Silver Creek, measurements of ... 151
Sinking Creek (South Fork Holston), features of ... 56-57
measurements of ... 53
Sinking Creek (Watauga), features of ... 87
measurements of ... 85
Sinks, occurrence and features of ... 39, 43, 78, 87
Skeenah Creek, measurement of ... 177
Skyuka Falls, N. C., view of ... 24
Smithwick Creek, measurement of ... 180
Smoky Mountains, features of ... 13-14
highest peaks in ... 14
Snow Creek (Nolichucky), measurement of ... 108
Snow Creek (North Toe), water powers of ... 113
Soil and vegetation, character and extent of ... 30-33
Soque River, measurements of ... 179
South Branch or Fork of any stream, *see* the stream.
South Indian Creek, features of ... 110
measurements of ... 108
South Saluda River, features of ... 137-138
measurements of ... 138
South Toe River, features of ... 114
measurements of ... 109
Splash dam, view of ... 108
Spring Creek (French Broad), features of ... 130
measurements of ... 128
Spring Creek (South Fork Holston), features of ... 59-60

Page.

Spring Creek (South Fork Holston), measurements of 53
Springs, occurrence and character of 19, 21, 39–40, 82
Sprucepine, N. C., road near, view of 36
Squirrel Creek (Nolichucky), measurement of 109
Squirrel Creek (North Toe), features of 113
Staleys Creek, features of 76–77
measurement of 73
Stanley Creek, measurement of 177
Steel Creek, features of 157
measurement of 152
Stekoa Creek, measurement of 178
Stink Creek, measurements of 177, 178
Stock raising, extent of 30–31, 41, 47
Stokes, H. G., acknowledgments to 11
Stony Creek (Watauga), features of 89
measurements of 86
Stony Creek (Yadkin), features of 165
measurements of 164
Stream flow, relation of forests to 30, 31–33
Stream measurement, methods of 34, 48
Suches Creek, measurements of 177, 178
Sugar Mountain, elevation of 153
Sumach Creek, measurement of 181
Sunflower River, measurement of 180
Swannanoa Rapids, view of 118
Swannanoa River, measurement of 128
Swannanoa River, North Fork, measurement of 128
Sweetwater Creek, measurement of 179

T.

Talking Rock Creek, measurement of 181
Tallapoosa River, measurements of 181
tributaries of, measurements of 181
Talona Creek, measurement of 181
Tate Creek, measurement of 179
Tellico River, measurements of 176, 177
Temperature, variation in 22–28
Tennessee River, features of 17–18
tributaries of, measurements of 176–177
Tessantee Creek, East Fork, measurements of 179
Thomas Creek, features of 57
measurement of 53
Three Fork Creek, measurement of 109
Threemile Creek, measurements of 108
Threetop Creek, measurements of 174
water powers of 174
Tickanetley River, measurement of 181
Tiger Creek, measurement of 178
Tiger River, measurement of 143
Toccoa River, measurements of 177, 178
Toe River, measurements of 108
Tombigbee River, measurement of 180
Topography, smoothly rounded, view showing 24
Town Creek (Hiwassee), measurement of 177
Town Creek (Watauga), features of 91
measurements of 86
Transportation, means of 47, 58, 83
See also Railroads.

Page.

Transylvania County, N. C., features of 116–117
Tuckasegee Falls, view of 176
Tuckasegee River, view of 176
water-power development on, view of 178
Tucker Creek, measurement of 128
Turkey Creek, features of 134
measurements of 128
Turkey Cove Creek, measurements of 151

U.

Unaka Mountains, features of 36–88
Upper Creek, features of 156–157
measurements of 151
Upper Laurel Creek, measurements of 86

V.

Valley Creek, measurement of 180
Valley of East Tennessee, features of 20, 38–39
Valley River Mountains, mean elevation of 13
Vegetation and soil, character and extent of 30–33

W.

Wahoo Creek, measurement of 179
Walker Creek, features of 75
measurements of 73
Walnut Creek, features of 132
measurements of 126
Watauga Lumber Company, forests of and lumbering by 27
Watauga River, drainage basin of 77–81
features of 18
measurements of 83–84
minerals in basin of 83
rainfall in basin of 81–82
springs in basin of 82
timber in basin of 82–83
transportation facilities in basin of 83
tributaries of, features of 87–95
tributaries of, measurements of 85–86
water powers of 84–85
Water resources, features of 17–20
Wateree River. *See* Catawba River.
Weaver Creek (Hiwassee), measurement of 178
Weaver Creek (South Fork Holston), features of 55
Wedstone Creek, features of 68
West Branch or Fork of any stream, *see* the stream.
Whiteoak Creek (Broad), measurement of 143
Whiteoak creeks (Nolichucky), measurements of 109
Whites Creek, measurement of 179
Whiteside Mountain, features of 22
view of 24
Whitetop Creek (Laurel Fork Holston), features of 66–67
Whitetop Creek (South Fork Holston), measurements of 62
Widner Creek, features of 67

Page.
Wildcat Creek, measurement of........... 181
Williams Creek, measurement of........ 177
Willieo Creek, measurements of.......... 180
Wilson Creek (Catawba), measurement of.................................... 152
Wilson Creek (New), measurements of.................................... 170
Wilson Creek (Watauga), measurement of.................................... 85
Wind Creek, measurement of............... 181
Wolf Creek (French Broad), features of. 129–130
Wolf Creek (Hiwassee), measurement of.................................... 177
Wolf Creek (South Fork Holston), features of.............................. 60–61
    measurements of......................... 53

Y. Pag

Yadkin River, drainage basin of........... 158–1
    features of................................ 1
    forests in basin of........................ 16
    measurements of........................... 16
    soils in basin of.......................... 160-16
    tributaries of, features of.............. 165–16
    tributaries of, measurements of......... 16
    water powers of........................... 162-16
Yahoola Creek, measurements of.......... 179
Yalabusha River, measurements of....... 180
Yellow Creek (Chattahoochee), measurement of.................................. 179
Yellow Creek (Etowah), measurement of. 180
Yellow Mountain, elevation of............. 13
Yonahlossee road, view of.................. 38
Young Cone Creek, measurement of...... 177

O

Pamphlets. SD425
Forest influences. P3
v.1

~~sent to BPD for mending 11/5/62~~
X-22-63
~~Frank Kang Rm 231~~
~~NOV 6 1963~~

~~M. Drenko 35 Mulford 11-12-66~~
~~JAN 1967~~

~~Hart FEB 2 1967~~

338428 SD425
P3
v.1
Forestry